THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

𝔑𝔢𝔴 𝔖𝔢𝔯𝔦𝔢𝔰.

VOLUME VIII.

CONTENTS.

VOL. VIII.

PART I.

PART II.

PART III.

PART V.

PAGE

PART VI.

DATES OF THE PUBLICATION OF THE SEVERAL PARTS
OF THIS VOLUME.

Part 1.—Containing pages   1 to 166.   (April, 1893.)

  ,,   2.   ,,   ,,   167 to 207.   (Sept., 1893.)

  ,,   3.   ,,   ,,   208 to 280.   (August, 1894.)

  ,,   4.   ,,   ,,   281 to 374.   (Sept., 1895.)

  ,,   5.   ,,   ,,   375 to 508.   (July, 1897.)

  ,,   6.   ,,   ,,   509 to 755.   (August, 1898.)

ERRATUM.

Pages 509, 525, at foot, *for* Scien. Proc. R.D.S., Vol. VIII., Part V., *read*
Vol. VIII., Part VI.

THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

CONTENTS.

The Authors alone are responsible for all Opinions expressed in their Communications.

Royal Dublin Society.

FOUNDED, A.D. 1731.   INCORPORATED, 1749.

EVENING SCIENTIFIC MEETINGS.

The Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and ready for transmission to the Editor.

SCIENTIFIC PROCEEDINGS

ROYAL DUBLIN SOCIETY.

———◆———

I.

POGOTRICHUM HIBERNICUM, SP. N. BY T. JOHNSON, D.Sc., F.L.S., Professor of Botany in the Royal College of Science, and Keeper of the Botanical Collections, Science and Art Museum, Dublin. PLATE I.

DURING an algological visit to the west coast of Clare in September, 1891, I found growing on young *Alaria* plants, at low water on the Duggerna Rocks at Kilkee, brown tufts of filaments, which, on subsequent microscopic examination, appeared to be different from any plant with which I was acquainted. I sent some of the material to Professor Reinke, of Kiel, with an accompanying suggestion that the plant might be *Litosiphon Laminariæ*, Harv., a suggestion which was not adopted. My plant was, in Reinke's opinion, a second species of a new genus, *Pogotrichum*, of which the other species, *P. filiforme*,[1] collected at Heligoland, had just been described by Reinke for his "Atlas deutscher Meeresalgen." A proof plate of *P. filiforme* was kindly sent to me for comparison. The Kilkee plant agrees in so many features with the Heligoland plant that I propose to call it *Pogotrichum hibernicum*.[2] Reinke's diagnosis of his genus *Pogotrichum* is as follows :—

"Unverzweigte, büschelformige, beisammenstehende, fadenför-

---

[1] J. Reinke, "Atlas deutscher Meeresalgen," II. Taf. 41, 1892.

[2] T. Johnson, Irish Naturalist, No. 1, p. 5, 1892

B

mige Thallome von radiär gebautem Querschnitt und intercalarem
Wachsthum. Vegetations-Fäden aus mehreren oder, doch seltener,
aus nur einer Längsreihe von Zellen gebildet. Pluriloculäre
Sporangien intercalar in den Thallus eingesprengt, nur aus einigen
der äusseren oder auch aus sämmtlichen Zellen eines Querschnitts
gebildet ; bei einreihigen Individuen durch Theilung einzelner
Gliederzellen in viele kleine Zellen entstanden.''

Pogotrichum hibernicum occurs on the thallus of *Alaria esculenta*,
Grev., in the form of numerous small *Elachista*-like tufts of fila-
ments, radiating from gall-like swellings (fig. 1). The individual
filaments of a tuft, not more than 1 cm. long, are seen, when
examined microscopically, to vary much in thickness, some being
only one cell thick, others many. All are provided with the usual
phæosporous hairs, scattered singly over their surface (fig. 3),
and all or nearly all the filaments are, judging from my material,
fertile, even when uniseriate. Each filament has at its apex one,
and, near its apex, usually several, of the just mentioned hairs.
The growth of the filaments is *intercalary*, trichothallic, as, *e. g.*,
in *Desmarestia*. Each filament, when examined in cross section,
shows itself to be *radially* constructed, solid or sub-solid, and with
its axial cells the largest. Further, each filament is unbranched,
as in *P. filiforme*, Reinke (fig. 3).

Though the filaments of a tuft are unbranched, and, to
this extent, unconnected with one another, they are, at their
lower ends, in close contact with one another, and more or less
fused into a compact body of a subparenchymatous nature. There
are, too, to be observed, growing out from the superficial cells at
the base of the filaments rhizoidal septate hyphæ which come into
contact with the surface of the *Alaria* thallus, and can, no doubt,
give rise to new *Pogotrichum* filaments. On making a vertical
section through the anchorage of *Pogotrichum hibernicum* it is seen
to be not merely applied to the surface of the *Alaria*, i. e. epi-
phytic, as a root-disc of a *Fucus* is to a stone, on which it grows.

The individual filaments of *P. hibernicum* penetrate into the
Alaria thallus, creep and ramify between both its cortical and
medullary cells, the limiting layer of the *Alaria* being frequently
obliterated during the process. Though I searched with $\frac{1}{24}$ mm.
objective, I was not able to see a host-cell into the cavity of

which a parasitic hypha had entered. A close examination of the sections gives every indication that these endophytic or intra-cortical hyphæ can, after creeping for some distance in the *Alaria* thallus, emerge at either surface to form new *Pogotrichum* tufts. This vegetative reproduction by means of stoloniferous endophytic hyphae, though distinctly novel in a brown alga, is not uncommon in parasitic Phanerogams (e. g. *Arceuthobium*,[1] *Pilostyles*[2]), in which plants their intra-cortical hyphae give rise to new plants at the external surface of their host-plants. Having been familiar for some time with the budding of the intra-cortical hyphae in *Arceuthobium* and other parasitic Phanerogams, it was not un-natural for me to see in the intra-cortical hyphæ of *Pogotrichum* a similar power of vegetative reproduction. My views were very much strengthened on reading a noteworthy paper by M. C. Sauvageau, which, under the title "Sur quelques algues phéos-porées parasites," has appeared this year[3] in the "Journal de Botanique." In this paper the few observations hitherto recorded of parasitic brown algæ possessed of endophytic hyphæ are summarised, and the interesting statement is made that the late Professor Harvey, of Trinity College, Dublin, was the first to record, in 1846, the penetration into the thallus of the host-plant by the filaments of a parasitic brown alga.[4] In 1850 and 1851 Thuret observed *Streblonema investiens*, Thur., sending endophytic filaments into the thallus of *Gracilaria compressa*, an observation repeated by Hauck in 1875. In 1872 Kny, at Heligoland, observed the endophytic filaments of an unidentified sterile brown alga in the thallus of *Delesseria sanguinea*, *Chondrus crispus*, *Laminaria saccharina*, &c. In 1875 Reinsch founded the genus *Entonema*, to include those microscopic *Ectocarpeæ* which grow parasitically on other *Phæophyceæ*, and on *Rhodophyceæ*, and send endophytic filaments into their thalli. In 1878 the most

---

[1] T. Johnson, "Annals of Botany," II.

[2] Solms Laubach, Das Haustorium d. Loranthaceen, &c., in Pringsheim's Jahrb. VI.

[3] C. Sauvageau, Journ. de Bot., Nos. 1–7, 1892.

[4] W. H. Harvey, Phyc. Brit., 1846–1851, Pl. 28, B. (The basal joints of the fila-ments of *Elachista velutina*, Aresch. (*Ectocarpus velutinus*, Kütz.), are represented penetrated into the thallus of *Himanthalia Lorea*, Lyngb.) *Elachista attenuata*, Harv. (*Myriactis pulvinata*, Kütz) is, more strictly speaking, the first brown alga figured (*op. cit.* Pl. XXVIII., A.) and described as truly parasitic.

distinct advance was made by Dr. Bornet,[1] who followed the
course of the endophytic filaments of the two species *Elachista
clandestina*, Crouan, and *Elachista stellulata*, Griff., and saw them
produce, some distance off, at the surface of the host-plant,
daughter tufts identical with the mother plant, from which the
endophytic stolons had grown. Bornet compared this develop-
ment with that of endophytic Fungi. The name *Herponema*,
proposed in 1880 by J. G. Agardh[2] for a genus to include three
species, *H. pulvinatum*, *H. maculans*, *H. velutinum* (*Ectocarpus velu-
tinus*, Kütz.), was adopted, with altered diagnosis, by Hauck[3] in
1885 for a group of species of the genus *Ectocarpus*, in which
group two of the species are *E. investiens* and *E. velutinus*, provided,
as previously mentioned, with endophytic filaments. The last
addition to our knowledge of parasitic *Phæophyceæ* is that made
by J. Reinke[4] in the *Sphacelariaceæ* of which the genus *Sphacelia*,
Rke., and five species of *Sphacelaria*, Lyngb., are described as
parasitic. Sauvageau commences an account of his own valuable
investigations with a more detailed description of the parasitism of
Elachista stellulata, Griff., a species which, in the hands of Dr.
Bornet, had, in 1875, been the means of a marked addition to our
knowledge of parasitic *Phæosporeæ*. Sauvageau describes how
the epidermis of the old plant of *Dictyota, dichotoma*, the host, is
destroyed, and how the cushion of *E. stellulata* rests on the medul-
lary layer of the host-plant, sending off radiating stoloniferous
hyphæ which ultimately reach the surface of the host-thallus, and
give rise to daughter tufts. The parasitic hyphæ penetrate into
the cavities of the host-cells without losing their chromatophores
or injuring the contents of the host-cells. Similar but less com-
plete observations were made on *Elachista Areschougii*, Crn., a
species which is parasitic on *Himanthalia Lorea*. In *Elachista
clandestina*, Crn., which is considered an *Ectocarpus*, the endophytic
hyphæ were readily seen connecting external tufts of filaments

[1] E. Bornet, "Études Phycologiques," p. 21. It is now known that *Elachista
Areschougii*, Crn., not *E. clandestina*, Crn., was examined.

[2] J. G. Agardh, "Till Algernes Systematik," p. 55.

[3] F. Hauck, "Die Meeresalgen," 1885, S. 324.

[4] J. Reinke, "Uebersicht der bisher bekannten Sphacelariaceen" (Ber. d. deut. bot.
Gesellsch. VIII., S. 201-215).

together. *Elachista fucicola*, Fries., growing on *Fucus vesiculosus* and *F. serratus*, *E. scutulata*, Duby, in the crypts of *Himanthalia Lorea*, and *E. pulvinata*, Harv., in the crypts of *Cystosira ericoides* and *C. discors* were found by Sauvageau to be epiphytic only. This observer also examined a number of species of *Ectocarpus*, *Myrionema*, &c., and found eight species of *Ectocarpus* penetrating into their hosts, to produce, by means of endophytic hyphæ, new tufts or patches of filaments. It would take us too far to give an account of these observations. Suffice it to say that six of the eight species have their diagnoses published for the first time. The species and their hosts are as follows :—

Ectocarpus velutinus,	Himanthalia Lorea.
Ectocarpus minimus,	H. Lorea.
Ectocarpus luteolus,	{ Fucus serratus. { Fucus vesiculosus.
Elachista clandestina, (Ectocarpus).	Fucus ceranoides.
Ectocarpus brevis,	Ascophyllum nodosum.
Ectocarpus Valiantei,	Cystosira ericoides.
Ectocarpus solitarius,	{ Dictyota dichotoma. { Taonia atomaria. { Dictyopteris polypodioides.
Ectocarpus parasiticus,	{ Ceramium rubrum. { Cystoclonium purpurascens. { Gracilaria confervoides.
Ectocarpus investiens,	{ Gracilaria compressa. { Gracilaria multipartita.

To return to *Pogotrichum hibernicum*, a simple inspection of the infested *Alaria* is enough to show that where the larger tufts of *Pogotrichum hibernicum* occur the host thallus has been disturbed, and a wart-like swelling produced. Microscopic examination shows that this swelling is formed partly of *Pogotrichum* and partly of *Alaria*, that a gall-like body[1] has been formed, just as in the case of the parasitism of *Ectocarpus Valiantei* on *Cystosira*

---

[1] Gall-like bodies have been described in *Rhodymenia palmata*, Grev., by Miss Barton (Journ. Bot., 1890), and in this and many other Florideæ by F. Schmitz, Bot. Zeit., 1892, No. 38 (Knöllchenartige Auswüchse an den Sprossen einiger Florideen

ericoides, and of *Streblonemopsis irritans* on *Cystosira opuntioides.*
As the tufts of *Pogotrichum hibernicum* are very numerous,
penetrate deeply into the host tissue, and occur, in my material,
on very young plants, it would seem that there is a possibility of
considerable injury being inflicted on the *Alaria*. Sauvageau
traces in the plants examined by himself a gradation of parasitism,
from the more or less symbiotic condition of *Streblonemopsis irritans*
on *C. opuntioides*, to the well-marked parasitism of *Ectocarpus
investiens* and of *E. parasiticus*, without seeing much indication of
injury to the host-plants, or of degradation of the parasite.

Reproductive Organs of P. hibernicum.—As already mentioned
every epiphytic or extra-cortical filament is, judging from my
material, fertile. One of the features which struck me most on
first examining the plant was the very great abundance of the
reproductive organs which are confined for the most part to the
free (upper) halves of the filaments. In this region the whole of
the superficial cells of the thick filaments, or in some cases, the
whole of the internal cells also, and all the joint-cells of the
uniseriate ones are not at all unfrequently converted into repro-
ductive cells. Thus the sporangia stand side by side more or less
continuously over the whole of the surface of the upper part of the
filaments. One cannot speak of definite sori of sporangia as one
does in such a plant as *Dictyota*. The zoosporangia are of two
kinds : unilocular and multisporous (figs. 3, 4) and plurilocular
(fig. 5). Both kinds occur in the same tuft, but not, so far as I
have seen, on the same filament. Unfortunately I know nothing
as to the fate of the zoospores. I hope to have an opportunity of
examining them at Kilkee in the coming year. On comparing
P. hibernicum with *P. filiforme*, Rke., it is found as described[1] by
Reinke, that *P. filiforme*, Rke., has no lateral Phæosporean hairs,
has plurilocular sporangia only, and is entirely epiphytic on
Laminaria saccharina. Its filaments are longer, thinner, and have
their plurilocular sporangia more localized than is the case in
P. hibernicum. As regards the absence of endophytic organs
in *P. filiforme*, a parallel case is presented by *Litosiphon*, one
species of which, *L. pusillus*, is epiphytic, the other, *L. Laminariæ*,

---

[1] J. Reinke, "Atlas deutscher Meeresalgen," ii. 3, 4 ; s. 62.

as pointed out by Reinke,[1] endophytic also. A more noteworthy example of an apparently important difference of habit in closely allied forms is described[2] by Sauvageau in *Ectocarpus fasciculatus,* variety *abbreviatus.* Two forms of this variety, growing on *Laminaria flexicaulis,* were examined; one is entirely epiphytic with abundant sporangiferous rhizoids, the other is endophytic also.

Affinities of Pogotrichum, Rke.—The affinity of *Pogotrichum* to *Litosiphon,* Harv., is so close, that Reinke in writing to me states that had he known of the Kilkee plant he would have hesitated before founding the genus *Pogotrichum.* In the last number of his " Atlas deutscher Meeresalgen," Reinke compares the four plants *Pogotrichum filiforme,* *P. hibernicum* ["the Johnsonian plant"], *Litosiphon pusillus, L. Laminariæ.* It is stated that—

1. The individuals with plurilocular sporangia, of *P. hibernicum,* agree with the filamentous specimens of *P. filiforme.*

2. The individuals with unilocular sporangia, of *P. hibernicum,* are like those of *L. Laminariae.*

3. Before, however, uniting the two genera it will be necessary to find plants of true *Litosiphon* species with plurilocular sporangia, like *Pogotrichum* individuals with plurilocular sporangia. (*P. filiforme,* with its plurilocular sporangia, is not, as one might suppose at first thought, the missing state of *L. pusillus* which is known up to the present with unilocular sporangia only).

4. Though the individuals of *Pogotrichum* consist of uniseriate as well as multiseriate filaments, those of *Litosiphon* are *always* multiseriate.

I have been enabled to examine dry, authentic material of *Litosiphon Laminariæ,* Harv., from the following sources :—

1. Through the kindness of Dr. E. P. Wright, Dublin, material of the type specimens, preserved in the Trinity College Herbarium, was at my disposal. One specimen was labelled "*Bangia laminariæ,* Lyngb. [and was collected by] Mr. Moore [the late Dr. D. Moore of Glasnevin] in Co. Antrim"; another " Ball and Thompson, 1834, Arran "; another " W. Andrews, Inch, Dingle Bay."

2. A specimen in the late Dr. D. Moore's own collection of

---

[1] J. Reinke, " Atlas deutscher Meeresalgen," *l. c.*

[2] C. Sauvageau, " Sur quelques algues phéosporées parasites," p. 38 (Journ. de Bot. VI., 1892).

Algæ of the N.E. coast of Ireland, 1834, for many years past in the Royal College of Science, Stephen's Green. This specimen was probably part of the same material as that from which Dr. Moore supplied Professor Harvey in the Trinity College Herbarium.

3. A specimen in the Herbarium of the Science and Art Museum, Kildare-street. I think it right to point out, before recording the result of my own examination of this material collected fifty years ago, first that the genus *Litosiphon* was founded in 1849 by Harvey[1] at the suggestion of Dr. Moore, who had noted the affinity of *Asperococcus pusillus*, Carm., and *Bangia Laminariæ*, Lyngb. ;[2] secondly, that Harvey in his description of *Litosiphon Laminariæ*, states that "the [peripheral] cells sometimes separate into four smaller cells which occupy the space of one cell." This condition is represented in the illustrations of the plant. Lyngbye, under *Bangia Laminariæ*, and J. G. Agardh, under *Asperococcus*[3] *Laminariæ*, speak of the "granula" being "quaterna" or "subquaterna" in *Litosiphon Laminariæ*. The chromatophores in the cells being granular, large, more or less parietal, and not unfrequently arranged, as seen from the outside, apparently in fours, made it difficult to distinguish between ordinary vegetative cells and the plurilocular sporangia. Having spent considerable time in the examination of this herbarium material I have been led to the following conclusions :—

1. That the filaments of *Litosiphon Laminariæ* are not always multiseriate as stated by Reinke; that uniseriate filaments, though young, sterile, and rare, do occur in the material examined.

2. That in some of the material, at any rate, all the filaments are fertile, as in *Pogotrichum hibernicum.*

3. That filaments with plurilocular sporangia are to be found sometimes in the same tuft with filaments producing unilocular sporangia.

4. That the filaments with plurilocular sporangia agree with the larger filaments of *Pogotrichum hibernicum* with plurilocular sporangia.

5. That the wart-like swellings and endophytic organs of *L.*

---

[1] W. H. Harvey, Phyc. Brit., Pl.   .

[2] Lyngbye, Tent. Hydrophy. Dan., Tab. 24, B., 4 figs, p. 84.

[3] J. G. Agardh, Sp. Alg., I., p. 79.

Laminariæ, already noted by Reinke, are similar to those of *P. hibernicum*. Thus I am led to believe that the two genera *Litosiphon* and *Pogotrichum* are one and the same, and ought to be united, and that *L. Laminariæ* and *P. hibernicum*, if not one species, are very closely allied. I prefer to go no further than this until I have had an opportunity of examining living material.

As regards the other affinities of *Pogotrichum*, it is a member of Kjellman's group *Encœliaceæ*,[1] containing amongst other genera, *Asperococcus, Scytosiphon, Punctaria, Desmotrichum*, and *Litosiphon*. *Pogotrichum*, like *Litosiphon*, is radially constructed, and thus differs from *Punctaria*, Grev., and *Desmotrichum*, Kütz. It should be remembered that *L. pusillus* may appear sub-bilateral in cross-section. The genus *Desmotrichum*, founded by Kützing,[2] suppressed by Thuret and Bornet,[3] and restored by J. Reinke,[4] is said to differ from *Punctaria* in having its phæosporean hairs solitary, and its sporangia projecting. Plate I., fig. 7, of *Punctaria* shows the plurilocular sporangia projecting very considerably. As the hairs, especially in young plants of *Punctaria*, may be solitary, and as Reinke[5] himself figures a section of *Desmotrichum undulatum*, J. Ag., showing three hairs side by side, it is probable that *Desmotrichum*, Kütz., ought not to be regarded as more than a sub-genus of *Punctaria*, Grev., a view in which I have, I am permitted to state, the support of Dr. Bornet. The affinity of *Pogotrichum* to *Stictyosiphon* is by no means remote. *Pogotrichum* might, with some reason, be described as an unbranched *Stictyosiphon*. A magnified figure of a *Pogotrichum* filament is not unlike a figure (natural size) of a *Stictyosiphon*, the hairs of *Pogotrichum* with their basal growth being regarded as potential branches,[6] it is not difficult to see how a plant of *Stictyosiphon* could be derived from a *Pogotrichum* filament.

---

[1] G. B. de Toni, "Systematische Uebersicht d. bisher bekannten Gattungen d. echten Fucoideen" (Flora, II. of Jahrg. 49, s. 171–182).

[2] Kützing, Tab. Phyc. VI., t. 4.

[3] Thuret et Bornet, "Études Phycologiques," p. 15.

[4] J. Reinke, "Atlas deut. Meeresalgen," I.

[5] J. Reinke, "Atlas deutscher Meeresalgen" (Taf. II., fig. 11), op. *ibid.*

[6] In one tuft of *Pogotrichum hibernicum* the apical hair of a filament from which the zoospores had escaped had grown in such a way as to form a new filament at the apex of the first.

Diagnosis of Pogotrichum hibernicum, sp. n.—Unbranched, tufted filamentous thalli, 1 cm. long, of radially constructed cross-section, and intercalary growth. Basal cells of filaments rhizogenous and penetrating *Alaria* thallus to give new tufts by endophytic hyphæ. Filaments hairy, each one assimilative and reproductive, solid or sub-solid.

Chromatophores granular, 4–20, parietal.

Sporangia unilocular and plurilocular in same tuft, but not in same filament, chiefly in upper parts of filaments, which part may become entirely converted into reproductive cells. Sporangia formed intercalarily, from individual joint-cells of thallus in uniseriate filaments, or from superficial cells, or from all the cells of multiseriate filaments. Fate of zoospores unknown.

Habitat.—On *Alaria esculenta,* Grev. (young plants) at Kilkee, Co. Clare, in September.

Affinities.—Very near to, if not identical with, *Litosiphon Laminariæ,* Harv.

THE LABORATORY, GLASNEVIN.

EXPLANATION OF PLATE I.

FIG. 1.—Tufts of *P. hibernicum* on *Alaria esculenta,* Grev., slightly magnified. The dark specks represent commencing tufts.

FIG. 2.—A portion of specimen of fig. 1, seen edgewise. Slightly magnified.

FIG. 3.—(*a*) Epiphytic part of a filament. × 60.
    (*b*) Cross-sections of various filaments. The more deeply shaded cells, *s*, represent unilocular sporangia, *s′*, emptied sporangium. × 240.
    (*c*) Basal region of epiphytic part of a filament, *r*, rhizoids. × 240.

FIG. 4.—*a* and *b*. Portions of two filaments showing unilocular sporangia. × 240.

FIG. 5.—Upper portion of a filament with plurilocular sporangia (*p. s.*); *p′. s′*, dehisced plurilocular sporangia. × 240.

FIG. 6.—Vertical section of *Alaria* thallus through *Pogotrichum* tufts. Slightly magnified.

FIG. 7.—Vertical section of thallus of *Punctaria,* Grev., showing plurilocular sporangia (*p. s.*) and hairs. × 240.

II.

NOTE ON THE ACTION OF PHOSPHINE ON SELENIUM DIOXIDE. By SIR CHARLES A. CAMERON, M.D.

A current of dry phosphine gas was conducted into a solution of selenium dioxide. Instantly a rich yellow precipitate began to form, but in about a minute it commenced to darken, and soon acquired a reddish hue from presence of precipitated selenium. I thought it possible, though far from probable, that a compound analogous to ammonium selenosomate ($NH_4SeO_2(NH_2)$) might be formed. It was clear that some body was formed by the action of the phosphine, first because of the deep yellow precipitate, and secondly because I found that an alcoholic solution of selenium dioxide could be made to completely absorb and retain a large quantity of phosphine. Owing, however, to the instability of the yellow compound, its composition could not be satisfactorily determined. Exposing it to low temperatures, and rigorously excluding atmospheric air from the solution in which it was formed, had no appreciable effect in retarding its decomposition.

The altered yellow substance when dried in vacuo became of a dull red colour, and its odour was very offensive, even for a selenium compound. It became black on being heated, and in part volatilized. On being boiled with nitric acid it was converted into a mixture of phosphoric and selenious acids, the latter slightly preponderating.

Phosphine does not precipitate all or even the greater portion of the selenium from the alcoholic solution of selenium dioxide. Generally the greater part of the selenium remains in solution. When phosphine ceases to act on the selenium oxide, and when the precipitated matter is filtered off, the filtrate is found to have a yellow colour. Evaporated in vacuo, a yellow oily body remains which is ethyl selenide ($(C_2H_5)_2Se$). A portion of the selenium which separates from the compound formed by the action of phosphine on selenium oxide exercises a reducing action on the alcohol, and produces ethyl selenide.

III.

THE USE OF THE PROTRACTOR IN FIELD-GEOLOGY.
By ALFRED HARKER, M.A., F.G.S.

In 1884 I showed that many of the little geometrical problems that arise in field-geology and mining can be solved graphically with the aid of a protractor.[1] As these earlier notes have been found of service in some quarters, it may be useful to give the following simplifications and extensions of the methods there followed.

The protractor employed is of the ordinary oblong form, and should be long in comparison with its breadth, so that the long edge may embrace as large an angle as possible, say 150°. This edge should be graduated in both directions from a zero-point in the middle. The distance from this zero-point of the mark corresponding to any angle will then be equal to the tangent of the angle, the breadth of the protractor being taken as unity, and this system of graduation may therefore be referred to as the tangent-scale. For some purposes it is convenient to have also a second system of graduation, in which the figures decrease both ways from 90° in the middle, and this we shall call, for a similar reason, the cotangent-scale.

Another instrument that will be occasionally of use is an ordinary scale of equal parts, graduated so that its unit is equal to the breadth of the protractor. Used in conjunction with the

---

[1] Geological Magazine, Dec. 3, 1884, vol. i., p. 154.

latter, it becomes a scale of secants or cosecants, according as we take the angle on the first or second of the scales of the protractor. The two instruments, as thus combined, are shown in fig. 1, the details of the graduations being omitted.
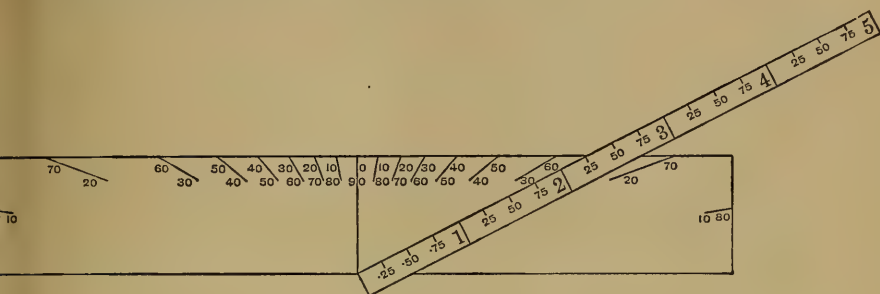
Fig. 1.

The diagrams by which the various questions are solved are for the most part of the nature of "gnomonic projections," but they are drawn with the protractor alone, and the *rationale* of each solution is easily grasped without any mathematical knowledge. The plane of the paper is supposed to be horizontal, and it will be seen that the inclination to this of any inclined plane can be completely represented in direction and amount by a straight line drawn from a fixed point O on the paper. For this purpose we take a plane parallel to the one in question, and passing through a fixed point C, not in the paper but beneath it, and at a distance below O equal to the breadth of our protractor. Through O we imagine a straight line drawn normal or perpendicular to the inclined plane and meeting the paper at the point P; then O P may be taken to represent the inclination to the horizon of the given plane. In practice this line is laid down on the diagram by simply laying the protractor on the paper with its zero-point at O and its edge in the given direction of inclination, and taking on the tangent-scale the given angle of inclination (fig. 2). To realize the explanation of the method, imagine the protractor placed instead in a vertical plane beneath the paper, its zero-point at O, and its graduated edge along OP; the centre from which the graduations radiate will then be at C, the point through which our inclined plane was drawn (compare fig. 3, supposed to be in a vertical plane, with fig. 2, the diagram actually used). In this

way a line such as OP, laid down simply by the aid of the pro-
tractor, may be taken to represent, both in direction and amount,
the slope of a hill-side, the dip of a bed, or the co-hade[1] of a fault
or lode.   If we are given the inclination of a plane to the vertical,
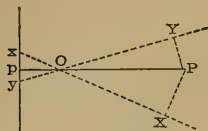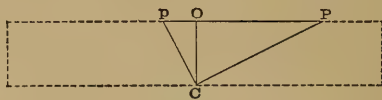
Fig. 2.   Fig. 3.

e. g. the hade of a fault, we use the cotangent- instead of the
tangent-scale of the protractor.   Of course the inclination of any
plane to the horizontal is equal to the inclination of its normal to
the vertical, and *vice versâ*.   By mentally supplying a picture like
fig. 3 to each of the diagrams, all the following solutions will
become evident.   In actual practice the protractor is, of course,
not placed in an upright position beneath the paper, but laid flat
upon it.

First we will suppose we have two inclined planes of given
inclinations, and wish to know in what direction and through
what angle one must be turned to bring it into the position of the
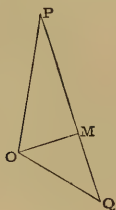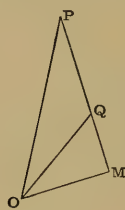
Fig. 4.   Fig. 5.

other.   By means of the protractor (tangent-scale) lay down OP
and OQ (fig. 4 or 5) to represent the inclinations to the horizontal
of the two planes : then the question is, what kind of tilt is
required to bring CP into the position CQ.   Draw PQ; this gives
the direction of the required tilt.   Draw OM perpendicular to

---

[1] The term hade seems to be correctly used for the inclination of a fault to the
vertical, and so the defect of this from 90° (co-hade) corresponds to dip, *i.e.*, inclination
to the horizontal.   Similarly, we may find it convenient to speak of the inclination of
a bed to the vertical as its co-dip, equivalent to hade.

PQ (produced if necessary), place the edge of the protractor along PMQ, with its zero-point at M, and read off the angle between P and Q. This is the sum or difference of the readings of the tangent-scale at P and Q, according as these points are on opposite sides or the same side of M, and it gives the amount of the required tilt. To see this, it is sufficient to imagine the protractor placed in an upright position beneath the line PMQ, with its zero-point at M. The following are some of the geological applications of this :—

(i). Strata originally inclined receive a new tilt: given the original and the final dip of the strata, to find the direction and amount of the new tilt.

(ii). Strata originally of known inclination receive a new tilt of given direction and amount: to find their final dip.

In this case draw OP to represent the original dip and a line PQ in the direction of the given tilt: then draw OM perpendicular to this line, and placing the edge of the protractor along PM with its zero-point at M, take the angle from P to Q equal to the angle of the tilt: then OQ represents the final dip.

(iii). Strata originally inclined have received a new tilt of known direction and amount, and their final dip is also known : to find their original dip.

This is merely the preceding question reversed.

(iv). Given the dip of a bed and the slope of a hill-side, to find the angle at which the bed meets the sloping surface.

Here we have only to draw OP to represent the dip and OQ the slope, and to take the angle between P and Q in the manner described above, the zero-point of the protractor being placed at M.

This result is merely approximate and for low angles, for the tilt was supposed to be about a horizontal axis.

We pass on to another class of questions, of which the general problem is : given, in direction and amount, the inclinations to the horizontal of two inclined planes, to find, in direction and amount, the inclination of their line of intersection. The construction is simple. Draw OP and OQ (fig. 4 or 5) to represent the inclinations of the two planes: then OM, drawn perpendicular to PQ, represents the inclination of their line of intersection. To make

this evident, imagine the whole to receive a tilt equal and opposite to that represented by OM : then by means of (11) we see that the two planes will be made to dip in opposite (or like) directions, and therefore their line of intersection will become horizontal. The following, among other questions, can be solved by the aid of this principle.

(v). Strata of known dip crop out on a hill-side of known slope : to find the direction of the outcrop.

Here (in fig. 4 or 5) if OP represent the dip and OQ the slope, OM will be the direction of outcrop.

(vi). Given the strike of the strata and the bearing of their outcrop on ground of known slope, to find the dip.

In this case draw OQ to represent the given slope and the line QP at right angles to the bearing of the outcrop to meet OP drawn at right angles to the strike ; this fixes P, and OP represents the dip of the strata in amount as well as direction.

(vii). Given the bearings of the outcrops of a bed at two spots on a hill, the slopes being different at the two spots and being known, to find the dip of the bed.
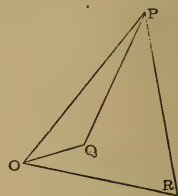
Fig. 6.

Here (fig. 6) draw OQ and OR to represent the two slopes, and from Q and R draw lines each at right angles to the bearing of the outcrop at the corresponding spot on the hill : these lines meeting in P, OP represents the dip of the bed. Of course the same considerations apply throughout to a fault or lode as well as to a bed, and it is needless to restate the various questions to suit this case. It should be observed, however, that if the inclination of the fault or lode be expressed with reference to the vertical (*i.e.* as a hade), we must use the second or cotangent-scale on the protractor.

(viii). Given the dips on opposite sides of a fold with inclined axis, to find the direction and inclination of the axis.

Here we regard the strata on opposite sides as inclined planes which meet in a line parallel to the axis of the fold. If OP and

OQ (fig. 4) represent the respective dips, OM, drawn perpendicular to PQ, will represent in direction and amount the inclination of the axis.

(ix). Given the hades of two lodes (in direction and amount), to find the direction and inclination of their line of intersection.

This is a similar case, except that, since we are dealing with inclinations of planes to the vertical, we must use the cotangent-scale. To read off the result as an inclination to the horizontal, we must, however, use the tangent-scale as usual. The two lodes are supposed not to strike in parallel directions.

Next we proceed to find the relation between the true dip of a bed and its apparent dip in any direction oblique to that of true dip. The inclined plane which meets the vertical diagram (fig. 3) along the line Cp, meets the horizontal diagram (fig. 2) along the line *xpy*, perpendicular to POp, and Op represents the co-dip of the inclined plane, or, in other words, is the distance corresponding to the dip of the plane reckoned on the cotangent-scale of the protractor. It is therefore easily laid down. Also, if any vertical plane through O meet the diagram-plane (fig. 2) in the line XO*x*, *x* being a point on our inclined plane, then O*x* represents in like manner the co-dip of the line in which this vertical plane cuts the inclined plane. We deduce the following constructions :—

(x). Given the true dip of a bed, to determine its apparent dip in any vertical section having a direction inclined to that of true dip.
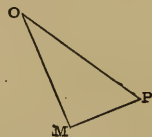
Fig. 7.

To do this draw OM (fig. 7) to represent the co-dip of the given bed ; that is, take the distance OM corresponding to the given true dip on the cotangent-scale of the protractor. Draw the line MP at right angles to OM, and draw OP in the given direction to meet MP at P. Then OP represents the apparent co-dip for a vertical section in that direction, and the apparent dip may be read off on the cotangent-scale.

(xi). Given the strike of a bed and its apparent dip in a certain direction, *e.g.* on the vertical wall of a cutting, to find the true dip.

C

Here draw OP (fig. 7) to represent the apparent co-dip in the given direction; draw PM in the direction of strike of the bed, and OM perpendicular to it; then OM represents the true co-dip of the bed.

(xii). Given the apparent dip of a bed in each of two given directions, *e.g.* on two vertical walls of a quarry, to find the true dip.

Draw OP and OQ to represent the two apparent co-dips; then draw PQ and OM perpendicular to it (fig. 4 or 5); OM represents the true co-dip of the bed.

In these last three questions we have used co-dips, and therefore the cotangent-scale of the protractor. It is easy to devise solutions involving only dips and the tangent-scale, but they are not quite so readily practised. Thus, for question (xii), draw OX and OY to represent the two apparent dips, and XP and YP perpendicular to them, meeting in P; then OP represents the true dip (fig. 2).

We pass on to a class of questions in which our second instrument is employed in conjunction with the protractor. The truth of the following solutions can be verified by simple diagrams. In actual practice the results are read off from the instruments themselves without the intervention of any diagram.

(xiii). Given the thickness of a bed or group of beds, to find the width of its outcrop, or *vice versâ.*

Here we suppose the angle at which the beds meet the surface of the ground to be known. For inclined strata on level ground it is the angle of dip; for horizontal strata on sloping ground the angle of slope; in any other case it is found as in (iv). The ratio of width of outcrop to thickness is the cosecant of this angle. To find it graphically we place the zero-point of the scale of equal parts on the centre of graduation of the protractor (fig. 1), and bring the edge of the simple scale to the proper angle as marked on the cotangent-scale of the protractor; then take the reading on the simple scale where its edge meets that of the protractor. We multiply or divide by this number according as the former or latter of the proposed questions is to be dealt with.

(xiv). Given the thickness of a group of beds, to find the
        depth it will occupy of a vertical boring, or *vice
        versâ.*

The ratio of the depth to the thickness is the secant of the
angle of dip, which we suppose to be known.   The method to be
followed is similar to the preceding, except that the angle is to be
taken on the tangent-scale of the protractor instead of the
cotangent-scale.

(xv). Given the width of the outcrop of a group of beds on
        level ground, to find the depth they will occupy of a
        vertical boring.

The ratio of the depth to the width of outcrop is the tangent
of the angle of dip (supposed known).   Place the edge of the
simple scale along that of the protractor, the zero-points of the
two coinciding.   Take the angle of dip on the tangent-scale, and read
off the corresponding number on the simple scale; this is the ratio
required.   To find the ratio of the width of outcrop to the depth
of the boring occupied by the beds, use the cotangent-scale instead
of the tangent-scale.

(xvi). A vertical shaft is sunk at a given spot: to find the
        depth at which it will strike a lode, the position and
        hade of which are known.

The ratio of this depth to the (known) distance of the shaft
from the outcrop of the lode is the cotangent of the hade, and is
found as in the preceding question, using the cotangent-scale of
the protractor.

(xvii). A vertical shaft is sunk at a given spot: to find at what
        depth it will strike the intersection of two known
        lodes.

The shaft is of course supposed to be sunk at some point on the
line of direction of the intersection, as determined in (ix).   The
distance of the shaft from the point in which the lines of outcrop
(produced if necessary) intersect is supposed known.   The ratio of
the required depth to this distance is the tangent of the angle of
inclination of the line of intersection, as determined in (ix).   This
ratio is therefore found as in (xv).

(xviii). To find the position and depth of the intersection of
two lodes with parallel strike.

The case of lodes with parallel strike, being excluded in the
foregoing, must be separately considered. Take OC
(fig. 8) equal to the breadth of the protractor, and on
a line at right angles to it lay off OP and OQ for the
hades of the two lodes, using the cotangent-scale.
We obtain thus a diagram drawn to scale representing
the lodes, PC and QC, and the depth of their intersec-
tion, OC, with the position of O relatively to the out-crops at
P and Q. The distance PQ between the outcrops being sup-
posed known, the other particulars can be determined by measure-
ment.

Fig. 8.

IV.

REPORTS ON THE ZOOLOGICAL COLLECTIONS MADE IN TORRES STRAITS BY PROFESSOR A. C. HADDON, 1888–1889.

PYCNOGONIDA (Supplement). By GEORGE H. CARPENTER, B.Sc., Lond., Assistant Naturalist in the Science and Art Museum, Dublin. Plate II.

[COMMUNICATED BY PROFESSOR HADDON.]

WHILE my paper on Professor Haddon's collection of Pycnogonida (*Sci. Proc. R. D. S.*, N.S., vii., pp. 552–3, Pl. XXII.) was in the press, three additional specimens, which had been inadvertently sent away with some corals, were returned to him, and handed by him to me. One of these was another example of the species *Ascorhynchus tenuirostris*, described in that paper. As the other two were not mentioned therein, and one of them seems new to science, I give an account of them in this supplementary paper. The list of works at the end of this paper must be considered as a supplement to my previous list, to works in which I shall refer by the numbers there given.

These specimens, like the former, were dredged between reefs off Murray Island in about 15 fathoms. They were obtained in December, 1888.

In my former paper, when enumerating the known species of *Ascorhynchus*, I omitted *A. japonicus*, recently described by Ives, whose paper (8) I have only just seen, and *A. armatus*, Wils. from the east coast of North America described (9) under the generic name of *Scæorhynchus*.

Family.—**PALLENIDÆ**.

Genus.—PALLENOPSIS, Wils.

This genus was founded in 1881 by Wilson (9) for the reception

of two North American species (*P. forficifer* and *P. longirostris*) with the general characters of *Phoxichilidium*, but with three-jointed chelifori, and ten-jointed false legs in both sexes. Hoek (1) admitted that this genus might possibly stand, in which case three of his "Challenger" species, described under *Phoxichilidium* (*P. oscitans*, *P. pilosum*, and *P. mollissimum*), would have to be transferred to it, and possibly a fourth, *P. patagonicum*, in which the basal joint of the cheliforus is indistinctly divided. But this latter species seems to forbid the use of the number of joints of the chelifori as a generic distinction in this group, and to oblige us to include in the genus *Pallenopsis* all the species hitherto referred to *Phoxichilidium*[1] which have ten-jointed false legs without claw and with simple spines, in both sexes, and which may be further characterised by their rather robust bodies with lateral processes not widely separated, the presence of rudimentary palpi in form of paired rounded prominences below the cephalic segment, and the presence of two auxiliary claws on the ambulatory legs. This view of the genus seems to be taken by Schimkéwitsch (7, 10).

The presence of false legs in both sexes places this genus in the family Pallenidæ as defined by Sars, but the simple nature of the spines on the false legs, and the extension of the cephalic segment over the proboscis (characters of much greater value), show its affinity to *Phoxichilidium*. Indeed, the genera *Parapallene* (suggested in my previous Paper) and *Pallenopsis* form such a connexion between the Pallenidæ and Phoxichilidiidæ of Sars, as will probably lead systematists to revert to the arrangement of Hoek and reckon both as one family—the Pallenidæ. In this family we have (as the one extreme) *Phoxichilidium* (which comes nearest to the Phoxichilidiidæ) connected by *Anoplodactylus*, *Pallenopsis*, and *Parapallene*, with *Pallene*, which leads on in the other direction to *Neopallene*, *Cordylochele*, and *Pseudopallene*, the latter genus occupying the frontier in the direction of the Nymphonidæ. Most of these relations have been already indicated by Schimkéwitsch (7).

---

[1] In addition to the species already mentioned, *P. fluminense*, Kr. and *P. Hoekii*, Miers.

Pallenopsis Hoekii (Miers).

Pl. ii., fig. 11.

Phoxichilidium Hoekii, Miers (11), p. 324, Pl. xxxv. B.

A single male was taken by Professor Haddon. Three males represented the species in the "Alert" collections obtained at depths from 4 to 17 fathoms, and all from various localities to the north of Australia. I give a figure of the terminal joints of a false leg, as in Miers' plate there is only a slightly magnified sketch of this appendage.

Family.—COLLOSENDEIDÆ.

Hoek's name for this family seems to me preferable to that adopted by Sars, which is derived from Goodsir's obscure genus *Pasithoe.*

Genus.—RHOPALORHYNCHUS, Wood-Mason.

This genus was founded by Wood-Mason (12) in 1873 for a species (*R. Kröyeri*) from Port Blair, Andaman Islands (25 fms.). Although Hoek (1) and Schimkéwitsch (7) consider that it should be sunk as a synonym of *Collosendeis*, Jarz., I venture to think that it may with advantage be revived for the reception, in addition to its type species, of *Collosendeis tenuissima*, Hasw. (4), from Port Denison, Queensland, and the new species from Torres Straits about to be described. It may be distinguished from *Collosendeis* by the elongation of the second and third trunk-segments, the extreme attenuation of the body, the slender stalk of the club-shaped proboscis, the excessive reduction of the caudal segment,[1] and the simple nature of the spines on the false legs. Moreover, the species of *Collosendeis* (in its restricted sense) seem characteristic of Arctic and Antarctic seas, and a depth of over 100 fathoms, whilst the species of *Rhopalorhynchus* are rather tropical and littoral. I feel, however, that the two genera are so closely allied that the discovery of species intermediate between them, which would necessitate their union, may be a very likely event.

---

[1] Haswell evidently saw and figured it in his species, though he wrote in the description that it had been lost.

Rhopalorhynchus clavipes, sp. nov.

Pl. ii., figs. 1–10.

Proboscis nearly as long as rest of body. Club of proboscis not quite half as long again as its stalk, with a single minute tooth on its dorsal surface; femora of ambulatory legs greatly swollen distally in a club-shaped form.

Length of the proboscis, 5 mm.; of the cephalic segment and trunk, 5·5 mm.; of a palpus, 7 mm.; of a false leg, 7 mm.; of an ambulatory leg, 20 mm.

A single female was taken by Professor Haddon.

This very remarkable species is readily to be distinguished from *R. tenuissimus* (Hasw.), by the shape of the proboscis, which in the latter species is more angular and has a larger dorsal tooth. Also the relative length of the proboscis in our species is longer, that of *R. tenuissimus* being only four-fifths as long as the rest of the body. In the regular club-shape of the proboscis *R. clavipes* closely resembles *R. Kröyeri*, from which species it may, however, be distinguished by having only one tooth (not two) on the dorsal surface of that structure (fig. 3). Moreover, there is no trace of a suture behind the oculiferous tubercle, such as Wood-Mason describes for *R. Kröyeri*. The cephalic segment is very short, with anterior processes where the palpi are inserted. The oculiferous tubercle resembles that of *R. Kröyeri* in form, being a cylinder with a short, pointed cone above; four large eyes without black pigment (fig. 3–4) are situated at the junction of the cylinder and the cone. The lateral processes of the cephalic segment are situated at its hinder extremity. The first and second trunk segments are elongated, the first being slightly the longer; these segments are cylindrical, very attenuated for the greater part of their extent, spreading into a "flange" anteriorly where attached to the segment in front, and broader also posteriorly where the lateral processes arise; these processes are cup-shaped. The third trunk segment is short (shorter relatively than in *R. Kröyeri*), and its lateral processes point backwards. Below it and directed downwards is the extremely small caudal segment (fig. 5), at the extremity of which the anus can be seen, in form a longitudinal

slit. The palpi reach well beyond the end of the proboscis; the first joint is globular in form, the second very short, the third very long (nearly as long as all the others together), the fourth short, the fifth half as long as the third, and the remaining five joints shorter, sub-equal, and bearing numerous very fine hairs (fig. 6). The false legs are equal to the palpi in length, the three basal joints and the fifth short, the fourth and sixth long, the former rather the longer and thickened distally, the four terminal joints evenly curved, the seventh, eighth, and ninth equally long, and the tenth rather shorter (fig. 7); the terminal claw is small, and does not form a cheliform arrangement as in *R. tenuissimus;* the spines are crowded together in several rows, they are scythe-shaped, and some show a trace of serration on the inner edge (fig. 8). The muscles for moving the joints of the false legs are shown in figs. 7 and 9. The ambulatory legs are all of equal length; the three coxal joints are short, of equal length, the two first cup-shaped, with their narrower ends together, and the third cylindrical; a genital pore opens on the ventral aspect of the second in all four pairs (fig. 5); the femur is straight and cylindrical, about six times as long as the coxal joints taken together, very slender for three-fifths of its length, and then swollen in form of a large club, nearly as large as the club of the proboscis; the first tibial joint is straight, cylindrical, and slender, slightly enlarged distally, rather shorter than the femur; the second tibial joint is rather shorter and more slender than the first; the tarsus and propodus are equal in length, together half as long as the first tibial joint, very slightly arched; the claw is rather more than half as long as the propodus and slightly arched (fig. 10). In *R. Kröyeri* the claw is figured nearly or quite as long as the propodus.

The size of the genital pores in this specimen, and its swollen thighs, show it to be a female. The swelling of the femora at the distal end only is remarkable, and it will be of interest to see, when the male is discovered, if its femora have anything approaching to this club-like form.

The joints of the ambulatory legs bear a few short feeble spines; otherwise the body is quite smooth except for the hairs and spines of the palpi and false legs.

It may be convenient to re-enumerate the five species collected by Professor Haddon; all the Pycnogonida at present known from the Torres Straits :—

PALLENIDÆ.

Parapallene australiensis (Hoek).
Parapallene Haddonii, Carp.
Pallenopsis Hoekii (Miers).

EURYCYDIDÆ.

Ascorhynchus tenuirostris, Carp.

COLLOSENDEIDÆ.

Rhopalorhynchus clavipes, Carp.

REFERENCES.

(8) IVES, J. G. :

"Echinoderms and Arthropods from Japan."—*Proc. Acad. Nat. Sci. Philadelphia,* 1891, p. 210.

(9) WILSON, E. B. :

"Report on the Pycnogonida" in the "Reports on the Results of dredging along the East Coast of the United States . . . by the . . . 'Blake,' 1880."—*Bull. Comp. Zool. Harv.* viii., 1881, p. 239.

(10) SCHIMKÉWITSCH, W. :

"Sur les Pantopodes de l'expedition du Vettor Pisani."—*Zool. Anz.* x., 1887, p. 271.

(11) MIERS, E. J. :

"Pycnogonida" in "Zoological Collections made in the Indo-Pacific Ocean during the Voyage of H. M. S. 'Alert,' 1881–2."—p. 323.

(12) WOOD-MASON, J. :

"On *Rhopalorhynchus Kröyeri*."—*Journ. Asiatic Soc. Bengal,* xlii., Part 2, 1873, p. 171.

EXPLANATION OF PLATE II.

Fig. 1. *Rhopalorhynchus clavipes*, female, natural size.

Fig. 2.   ,,   ,,   ,,   dorsal view, × 6.

Fig. 3.   ,,   ,,   lateral view of cephalic segment and proboscis, × 6.

Fig. 4.   ,,   ,,   dorsal view of oculiferous tubercle, × 18.

Fig. 5.   ,,   ,,   ventral view of third trunk segment, caudal segment, and coxal joints, × 8.

Fig. 6.   ,,   ,,   palpus, portion of fifth and last five joints (1 in. obj.).

Fig. 7.   ,,   ,,   false leg, portion of sixth and last four joints (1 in. obj.).

Fig. 8.   ,,   ,,   spines of false leg ($\frac{1}{6}$ in. obj.).

Fig. 9.   ,,   ,,   false leg, fifth and portions of fourth and sixth joints (1 in. obj.).

Fig. 10.   ,,   ,,   tarsus and propodus of ambulatory leg (1 in. obj.).

Fig. 11. *Pallenopsis Hoekii*, male, false leg, portion of sixth and last four joints (1 in. obj.).

V.

ON THE GERMINATION OF SEEDLINGS IN THE ABSENCE OF BACTERIA. By H. H. DIXON, B.A.

THIS paper contains a description of experiments on the possibility of germination in the absence of Bacteria. It was found that seeds, the outer coats of which were sterilized, germinated in the absence of Bacteria, and being kept absolutely free from Bacteria did not, after growth had ceased, suffer the decay of death, but remained for more than twenty months apparently unchanged. An apparatus for sterilizing the outer coats of the seeds, and sowing them without the introduction of Bacteria, is described in the paper.

<div align="center">VI.</div>

A LIST OF SOME OF THE ROTIFERA OF IRELAND. By MISS L. S. GLASCOTT. Plates III. to VII.

Prefatory Remarks.

The following list of Irish Rotifera is the result of but six months research, from May to October in 1891. The number of rare and new species obtained during this short period points to the conclusion that the Rotifera are well represented in this country, and I have been induced to publish this list, imperfect as it is, in the hope that it may lead other observers to study the group.

Thanks to the beautiful monograph of " The Rotifera or Wheel-animalcules," by Dr. C. T. Hudson, and the late Mr. P. H. Gosse, F.R S., the labour of studying Rotifera is reduced to a minimum. In this paper I have enumerated my captures in the same order as that given in the Monograph, and to facilitate reference I have given in brackets the page, plate, and figure where each species is described and figured in that Monograph. With respect to the new species, it is hoped that sufficient details are given to permit of their recognition should they be met with by others who may have better opportunity to submit them to closer scientific examination. The roughness of the accompanying sketches, which I have endeavoured to make of them, demand an apology, but my ignorance of the art of drawing must be my excuse.

In conclusion, I wish to offer my best thanks to Professor Haddon, of Dublin, at whose suggestion I took up the study of this interesting group, and without whose kind encouragement and ready help this list would not be now forthcoming ; also to Mr. C. Rousselet, F.R.M.S., London, to whom I am indebted for much valuable advice with regard to the best means of capturing

and examining species, and to several other kind friends who have forwarded me specimens from distant countries.

TABLE OF SPECIES.

Floscularia regalis, Hudson.

[The Rotifera, vol. i. p. 49, Pl. I. fig. 8.]

Several of this species occurred attached to the leaflets of *Myriophyllum* and *Lemna trisulca*, from a marsh drain exposed to the influence of a tidal river and also upon the leaflets of *Sphagnum* from a bog. In some cases there were two or three eggs adhering to the base of the foot within the tube. The species is said to be not common; the seven knobbed lobes of the corona afford a good specific feature.

Habitat.—A marsh drain, Co. Wexford.

Floscularia ornata, Ehrenberg.

[The Rotifera, vol. i. p. 50, Pl. I. fig. 9.]

Habitat.—Frequent in bogs, ponds, and deep drains, Co. Wexford.

Floscularia cornuta, Dobie.

[The Rotifera, vol. i. p. 51, Pl. I. fig. 7.]

Frequent. The long tapering dorsal lobe is usually curved backward when the coronal cap is expanded.

Habitat.—Ponds, bogs, and drains, Co. Wexford.

Floscularia campanulata, Dobie.

[The Rotifera, vol. i. p. 52, Pl. I. fig. 1.]

Frequent. The voracity of this species fully equals that of *Floscularia ambigua*. On one occasion, as I was watching the struggles of an unfortunate little *Colurus obtusa* which had been engulfed into the already closely packed stomach, a *Diaschiza Hoodii*, almost as large as the Floscule itself, came sailing above. Down it rushed headlong into the vortex; but alas! even the throat of a Floscule has its limits, and in spite of every effort made to swallow it, the prize stuck fast, head downward, heels kicking frantically above, until finally it was released, and went on its way rejoicing.

Habitat.—Pond and bogs, Co. Wexford.

Floscularia ambigua, Hudson.

[The Rotifera, vol. i. p. 53, Pl. I. fig. 2.]

Frequent. The lateral lobes in every case reduced to mere undulations.

Habitat.—Ponds, bogs, and drains, Cos. Wexford and Waterford.

Floscularia algicola, Hudson.

[The Rotifera, vol. i. p. 54, Pl. II. fig. 1.]

I have found this tiny member of the family several times, attached to small clumps of *Gloiotrichia* growing upon the stems of water-plants, as described by Dr. Hudson, and also adhering to the leaves of other small aquatic plants, such as *Calletricha, Lemna*, &c., but it is by no means common.

Habitat.—Bogs and ponds, Co. Wexford; the Canal, Dublin.

Melicerta ringens, Schrank.

[The Rotifera, vol. i. p. 70, Pl. V. fig. 1.]

Abundant in ponds, adhering in colonies to the stems of water plants. In one instance I noticed many empty tubes of large size, the recent occupants lying about not far distant, the long wrinkled foot looking so strangely naked without its habitual covering. Whether it is customary with the species thus to forsake their tubes at certain seasons of the year, or whether it was due on that occasion to some discontent with their surroundings, I do not know. The occurrence suggests investigation.

Habitat.—A pond, Co. Wexford.

Melicerta conifera, Hudson.

[The Rotifera, vol. i. p. 72, Pl. V. fig. 2.]

A large specimen seated upon the stem of a plant *without* a tube, the body so contracted as to entirely conceal the foot. The lobes of the corona were fully expanded, and did not exceed the width of the body; the long pointed chin was likewise observable. At some little distance there was an empty tube of about the same circumference, but of greater length, the long conical pellets of which sufficiently denoted the species to which it belonged.

Habitat.—A pond, Co. Wexford.

Limnias annulatus, Bailey.

[The Rotifera, vol. i. p. 77, Pl. VI. fig. 2.]

Two of this rare species occurred upon the leaflets of *Utricularia vulgaris.* I have mounted them *in situ* in glycerine jelly. The transverse ridges of the tubes show out beautifully; the head of one of the creatures is bent sideways in the tube, and shows the horny processes. In order to kill them I applied a drop of hot water to the edge of the cover glass, which was laid over the plant on which they were fixed, whereupon they immediately expanded the lobes of the corona, and set the wheels in motion with glorious vigour, which, with a spot-lens, afforded a most interesting sight to the beholder. I subsequently killed them by applying the glycerine jelly, which at the same time preserved their bodies.

Habitat.—A deep marsh drain, Co. Wexford.

Œcistes crystallinus, Ehrenberg.

[The Rotifera, vol. i. p. 80, Pl. VII. fig 3.]

A very common species. I have met with large colonies embedded in the gelatinous balls of *Gloiotrichia* which infests some water-plants; also single specimens in various situations. When they adopt the *Gloiotrichia* for their dwelling-place the tube is simply continued from the surface of the plant to protect the upper portion of the animal. It is of loose, gray, fluffy texture, and very unsymmetric in shape.

Habitat.—Bogs and ponds, Cos. Wexford and Waterford.

Œcistes longicornis, Davis.

[The Rotifera, vol. i. p. 82, Pl. VII. fig. 6.]

The tube of this species was much more compactly built than that given in the description in the Monograph. It was smooth, cylindric, and tapered towards the base, which was attached to a leaflet of *Utricularia vulgaris.* The body of the animal was half the length and size of the tube, and supported by a slender foot. The antennæ were very long, with a small joint at the tip, and spread widely apart; the coronal disc was small and almost circular, with a wide ventral gap; there were two long, oval eggs placed end to end in the lower half of the tube, which were but dimly discernible through the semi-opaque wall, which was of an orange colour. The creature was extremely timid, and retreated within the tube upon the slightest alarm.

Habitat.—A marsh drain, Co. Wexford.

Œcistes brachiatus, Hudson.

[The Rotifera, vol. i. p. 83, Pl. IX. fig. 2.]

Three of this well-marked species occurred, two among filaments, and one attached to a moss leaf. The dark branching ribs, which spread over the walls of the coronal cup, give it a very distinctive appearance.

Habitat.—A pond, Co. Wexford.

Œcistes velatus (Gosse).

[The Rotifera, vol. i. p. 83, Pl. D. fig. 8.]

I have met with this species, which is noticed as of rare occurrence by Mr. Gosse, frequently, but in no instance has it attained to any remarkable size or striking beauty. Always wandering, the corona is usually maintained expanded, and is of somewhat square outline. The very opaque *black* eyes, set widely apart in the neck, close to the corona, arrests the attention at once, as does also the very dark contents of the intestine (?), which seem to be invariably present. The creature in all respects resembled the figure, and in some instances the form of the trophi was quite distinct.

Habitat.—A pond, a bog, Co. Wexford.

Philodina erythrophthalma, Ehrenberg.

[The Rotifera, vol. i. p. 99.]

Frequent. Cos. Wexford and Waterford.

Philodina roseola, Ehrenberg.

[The Rotifera, vol. i. p. 99, Pl. IX. fig. 4.]

Frequent.

Habitat.—Ponds and ditches, Cos. Wexford, Waterford and Kerry.

Philodina citrina, Ehrenberg.

[The Rotifera, vol. i. p. 100, Pl. IX. fig. 6].

Not uncommon. The truncate body and abrupt foot sufficiently mark off the species from its congener. Cos. Kerry and Wexford.

Philodina megalotrocha, Ehrenberg.

[The Rotifera, vol. i. p. 101, Pl. IX. fig. 7.]

Rare.

Habitat.—Ponds and streams, Co. Wexford.

Philodina aculeata, Ehrenberg.

[The Rotifera, vol. i. p. 101, Pl. IX. fig. 5.]

This species is apparently subject to great variation with regard to the development of the spines, and also with respect to

colour. I have met with many examples answering to the descrip-
tions of each of the authorities quoted in the Monograph.   In the
long-spined variety (Plate IX. fig. 5) the number varies from
two to three in the first row, but the two central spines in the
succeeding row are always highly developed.   I have seen them
moved independently up and down, as though under the control
of special muscles. Also in one instance I noticed that the upright
lateral spines were not visible, but whilst I watched, the creature
suddenly assumed a sitting posture, and the spines, which had lain
flat against the sides of the body, were flung upward with a jerk,
and after some time were withdrawn entirely into the integument,
and I found one example with no spines at all.

   With regard to the short-spined variety, Dujardin's description
" tout herissé d'épines " is most appropriate.   At the juncture of
every segment there is a closely set row of short, pointed, upright
spines, which continue round toward the ventral surface.   These
cause the body, in many instances, to be so overlaid with sediment
that it is difficult to discern them.   There is a considerable diffe-
rence between these two varieties.   In the latter, or short-spined
variety, the body is deeply corrugated longitudinally, and though
there is a notable swelling in the central segment, the succeeding
portion does not terminate abruptly towards the base of the foot
as in the former, but descends gradually; the toes are also very
small.   The colour is sometimes white, but generally shades from
light amber to brown.   Its manners are slow and timid, as it crawls
into the axils of moss leaves, and persistently hides itself therein.

   Habitat.—Ponds, bogs, and streams, Cos. Wexford and Water-
ford.

Rotifer vulgaris, Schrank.

[The Rotifera, vol. i. p. 104, Pl. X. fig. 2.]

Common everywhere.

Rotifer macroceros, Gosse.

[The Rotifera, vol. i. p. 105, Pl. X. fig. 5.]

   Though not common, several fine examples have occurred.
The unusual length of the antenna, its forward direction and

strange wagging movement denote the species unmistakably. It is very timid, and shrinks under cover on the slightest alarm. In one instance it was seated in a little nest in a small heap of flock adhering to the stem of a water-plant, from which it cautiously protruded its head, and wagged the long antenna in a knowing manner.

Habitat.—A bog; a marsh drain, Co. Wexford.

Rotifer hapticus, Gosse.

[The Rotifera, vol. i. p. 106, Pl. X. fig. 3.]

Only one specimen occurred during a whole summer's research. *Habitat.*—A marsh drain, Co. Wexford.

Rotifer macrurus (?), Schrank.

[The Rotifera, vol. i. p. 107, Pl. X. fig. 4.]

The body very large, *smooth*, and colourless, and well marked out from the foot; when extended there was always a waist-like attenuation just under the mastax, as described of *Philodina roseola.* In the intestine—a large oval chamber—a mass of coloured granules rotated, and close to the foot the beat of the contractile vesicle was plainly visible, occurring at distant intervals. The collar was thick and bulging, the lobes of the corona of splendid size, with a deep V-shaped sulcus between them; when it was expanded, the column was not visible. The foot—composed of 7 or 8 joints—was stout, and capable of immense extension. The toe and spurs were of moderate length. Its manners were sluggish, remaining for lengthened periods as if asleep, then slowly unfurling the lobes of the corona, it set the cilia in motion for a short time, and then again relapsed into a quiescent state. There were two of this species close together, and in neither could I detect the slightest trace of eyes. Although not agreeing in all particulars with the description of the above-mentioned member of the genus given in the Monograph, it seems to approximate closely to it.

Habitat.—A pond, Co. Wexford.

Rotifer phaleratus,[1] sp. nov.

[Pl. III. fig. 1.]

Sp. Ch.—Body translucent, tapering gradually from the shoulders, which are broad, and ornamented with a conspicuous pear-shaped marking.

This species is probably only a variety of *R. vulgaris*, which it resembles in most particulars, but it is much broader at the shoulders (or that part of the body immediately behind the neck), which are ornamented with a broad, dark, pear-shaped marking, apparently confined to the outer integument, as it shows no change of position during the movements of the internal organs. As I was obliged to sketch in the head from memory, the details of that part are not reliable. Three of these creatures occurred from the same dip.

Habitat.—A stream, Co. Wexford.

Callidina elegans, Ehrenberg.

[The Rotifera, vol. i. p. 109.]

The hooked proboscis on the tip of the column—a distinctive feature in the species—was not minute, as described in "The Rotifera," but quite prominent. The body was large and heavy, the central segment greatly swollen, and marked out by deep constrictions. It was of a dirty white colour; its manners were sluggish, crawling slowly and heavily amongst the rubbish, in which it sought to conceal itself. There were, of course, no eyes—about the most inelegant species I have met with.

Habitat.—A pond, Co. Waterford.

Callidina bidens, Gosse.

[The Rotifera, vol. i. p. 109, Pl. X. fig. 8.]

At my first introduction to this species it was boldly walking across an open space with regular stride, using foot and mouth as does the larva of a *Geometra*. As soon as it approached a neighbouring cover, however, it was glad enough to take refuge therein, and withdrawing the foot sat comfortably down on a broad base,

---

[1] Phaleratus, "with ornaments on the shoulder."

stretched out the long tapering neck, unfurled the corona, and commenced to resuscitate exhausted nature with an ample meal. In this position the transverse corrugations of the integument were plainly visible, as was also the exceptionally long buccal funnel. The species is said to have no eyes, and certainly none were apparent; yet I noticed that as soon as it neared the coloured mass of sediment it *altered its course*, and made straight for it with evident purpose; the boldness of its stride also seemed hardly that of a creature dependent on the sense of touch alone for guidance.

Habitat.—Streams and ponds, Cos. Wexford and Waterford.

Callidina bihamata, Gosse.

[The Rotifera, vol. i. p. 111, Pl. X. fig. 7.]

Quite a number of these occurred in bog moss from Kerry. The very short dorsal antenna and its backward direction affords a good feature for identification.

Habitat.—Bog moss, Co. Kerry; a pond, Co. Wexford.

Adineta vaga (Davis).

[The Rotifera, vol. i. p. 112, Pl. X. fig. 10.]

Of peculiar interest, there being only two species of the genus. It was busily searching for food, and the strange manners described by Dr. Hudson were in full operation. The clear channel dividing the head into two halves was conspicuous.

Habitat.—Amongst Confervæ on the walls of a well, Co. Wexford.

Microcodon clavus, Ehrenberg.

[The Rotifera, vol. i. p. 118, Pl. XI. fig. 1.]

When I first saw this morsel of exquisite beauty it was swaying about between two leaflets of *Myriophyllum*, attached, as Dr. Hudson shrewdly guesses, by a slender foot-thread to a tiny heap of flock. As the light was fortuitous, I distinctly saw this line, and furthermore it was clearly demonstrated by tiny atoms of flock which adhered to it in several places throughout its length, all of which responded in concert to the swaying of the animal. The creature remained in the same spot for more than an hour, occasionally changing its point of attachment until there was quite

a little web spread about, against a bar of which it finally attached itself by the middle of the foot, swung round and round head over heels with great rapidity, a most amusing sight; then a sudden dart of lightning speed, and it was gone. I found it again, but it had grown wild and restless, and we soon bid adieu forever. Since then I have met with numbers of them from two different localities; they bear confinement well, and increased rapidly in a large pan into which I had thrown the water containing them. The representation of the species in the Monograph is so truthful both in form and colouring that it leaves me little to say. The stomach always appeared to be distinctly two-chambered, the lower chamber being about two-thirds the size of the one above it, the line of division marked by a slight constriction, and also by the *different condition of the contents*. The bright red organ *mostly* present was even larger than given in the figure alluded to, and unsymmetric in shape, but examples also occurred in which it was absent; and in the latter case the whole body was invariably studded over with globules, some of which were tinged with yellow, and had an oily appearance. The coronal disc, though always open, was rarely expanded to the plate-like flatness represented in the above figure. I have seen it suddenly close over an atom within the circle to prevent its escape. The margin of the disc invariably swept down in an open V-shaped curve to a point upon the breast.

Both the under and upper surface of the mastax were deeply tinged with purple, looking like two transverse purple plates, upon the latter of which rested the large purple eye. Occasionally I detected a low dorsal ridge, running from under the dorsal antenna to the base of the foot. The ovary was always of large size, and remarkably clear; the contractile vessel was well defined.

Habitat.—A bog, a drain, Co. Wexford.

Microcodon (?) robustus, sp. nov.

[Pl. III. fig. 2.]

Sp. Ch.—Body smooth, cylindric, stout; corona of the same diameter as the trunk; foot almost as long as the body; toe single, stout, and acutely pointed.

This species most probably belongs to the family Microcodidæ,

though quite a giant as compared to its hitherto sole representative
M. clavus. We have the same contour of the body, the same long
foot continuous with the trunk and terminating in a single acutely
pointed toe, the same upright position, hovering motion, and per-
manently expanded disc of that species. The latter, however, was
not produced into a flattened rim, but remained always of the same
circumference as the body, the margin being interrupted by many
depressions and elevations. The interior of the cup also contained
some cushion-like prominences, somewhat similar to those of *Hy-
datina senta.* I regret that I can only give a proximate idea of
these outlines as the creature disappeared from view before my
observations were completed. There were two prominent projec-
tions on the margin of the disc toward the centre of the ventral
aspect which were most probably the ventral antennæ. Depressed
at the sides the margin then swept upward in waving curves to a
dorsal elevation, at the back of which was seated the tuberculate
dorsal antenna. There appeared to be a wide-spread brain, which
dipped downward in the middle; and from the centre of the cup
there gleamed a large red eye. I could not discern the trophi. An
ample stomach was surmounted by two clear globe-shaped gastric
glands, which were very conspicuous. The body was smooth, cylin-
dric, but somewhat flattened ventrally, and of a dull amber colour.
It hovered about in an upright position, and made little jerks for-
ward, as though snatching at tiny atoms of food. Length, about
$\frac{1}{100}$th of an inch.

Habitat.—A ditch, Co. Wexford.

Sacculus viridis, Gosse.

[The Rotifera, vol. i. p. 124, Pl. XI. fig. 2.]

Not unfrequent. Trophi often protruded with a snap.
Habitat.—Ponds and deep drains, Co. Wexford.

Synchæta pectinata, Ehrenberg.

[The Rotifera, vol. i. p. 125, Pl. XIII. fig. 3.]

Not common.
Habitat.—Ponds, Co. Wexford.

Synchæta tremula, Ehrenberg.

[The Rotifera, vol. i. p. 128, Pl. XIII. fig. 2.]

Not common.   A few examples only occurred.

Habitat.—A marsh drain, Co. Wexford; a stream, Co. Waterford.

Hydatina senta, Ehrenberg.

[The Rotifera, vol. i. p. 9; vol. ii. Pl. XIV. fig. 1.]

Crowds of splendid examples of this interesting species occurred in a small duck-pond, in the month of July, in company with *Notops hyptopus*, many of which (the *Hydatina*) were affected by the fungoid disease alluded to by Dr. Hudson.   The internal parasite also noticed by him seemed quite of common occurrence; in one specimen, which had been recently killed on the slide by the rays of the sun, there were no less than three of these curious pear-shaped creatures tumbling madly over each other in their desperate efforts to escape from the body of their dead host; they finally effected their escape by making their exit through the mouth.   I searched the same pond again in the month of September, and there was not one *Hydatina* to be found: they had entirely disappeared.

Habitat.—A duck-pond, Co. Waterford.

Notops hyptopus (Ehrenberg).

[The Rotifera, vol. ii. p. 13, Pl. XV. fig. 2.]

As before stated this species occurred in swarms in a duck-pond in company with *Hydatina senta*.   The wobbling gait, the curved edges down the dorsal surface, and the truncate corona bulging forward toward the centre, afford satisfactory points for identification.   It also occurred in other localities, but only as isolated specimens.   In all cases there were two distinctly separate red eyes (cervical), placed, however, so close together as to appear like one.   Their ultimate union would not be improbable.

Habitat.—Ponds, bogs, and streams, Cos. Waterford, Wexford, and Kerry.

Notops (?) **quadrangularis**, sp. nov.

[Pl. III. fig. 3.]

Sp. Ch.—Body quadrangular; head narrow; foot long and non-retractile; toes nearly as long as the foot, furcate.

Approaching *N. brachionus* this species still bears too many distinctive characteristics to be confounded with it, the much narrower head, the high shoulders, straight sides of the body, and comparatively long toes being subject to no variation in the many examples which occurred.   At the four corners of the trunk there are dark gray or brown patches seemingly spread out upon the ventral floor which, under a high power, appear to be globulated, foliaceous expansions, such as we see in *Pterodina*.   The truncate head is simple, and bears no styligerous prominences.   A single large red eye is situated close to the frontal margin.   The large forcipate (?) trophi reach deep into the neck, from the posterior end of which spreads an ample stomach, with wide, flat ovary underneath.   The foot is long, round, and non-retractile, the pointed toes being almost of equal length.   Length about $\frac{1}{70}$th of an inch.

Not unfrequent.

Habitat.—Ponds and streams, Cos. Wexford and Waterford.

Taphrocampa annulosa, Gosse.

[The Rotifera, vol. ii. p. 16, Pl. XVII. fig. 12.]

Very common.   I have seen it as described and figured in Pl. XVII. fig. 12, of the Monograph, but far more frequently the body presented a depressed and collapsed appearance, with a deep broad groove along the dorsal line, the annular ridges conspicuously raised, and the lateral depressions (Pl. XVII. fig. 12*b*) deeply marked. The sedimentous deposit adhering to the surface of the integument denoted that this appearance was a reality, and not due to an optical delusion.   The black brain mass was always conspicuous, but no red eye occurred.   The *auricles* were frequently everted, especially when the animal swam in the open.   The foot, if rightly so called, was mostly crescent-shaped, and in all cases appeared to

be but a furcate projection of the ventral integument, and incapable of independent movement, the rounded lobe in the middle of the crescentic fork being situated *distinctly above it*, and hence to be regarded as a true tail; this was especially evident on one occasion, as the creature curled itself round a slender stem, when the crescent was bent underneath, leaving the tail projecting above it.

Habitat.—All fresh waters, Cos. Wexford, Waterford, and Kerry.

Taphrocampa Saundersiæ, Gosse.

[The Rotifera, vol. ii. p. 18, Pl. XVII. fig. 11.]

I had but a moment's glimpse of this species as it hurried into cover, but the ridged annulations of the body, the lumpish head, narrow neck, and the shape of the toes sufficiently proved its identity.

Habitat.—A stream, Co. Wexford.

Pleurotrocha gibba (?), Ehrenberg.

[The Rotifera, vol. ii. p. 20, Pl. XVIII. fig. 5.]

This is undoubtedly the species figured by Mr. Gosse. The large head curving to the oblique disc, the short body, the single foot-joint stout, but distinct; toes a trifle longer than the foot: all coincide so as to render its identity indisputable; its manners were slow, as it persistently grubbed amongst the flocose.

Habitat.—A stream, Co. Waterford.

Notommata aurita, Ehrenberg.

[The Rotifera, vol. ii. p. 21, Pl. XVII. fig. 6.]

Common.

Habitat.—Stream, ponds, Cos. Waterford and Wexford.

Notommata ansata, Ehrenberg.

[The Rotifera, vol. ii. p. 21, Pl. XVII. fig. 3.]

The great rapidity of movement in this species renders it a difficult one to study. I could not detect the eye; but the brain, though clear, was well defined. The contents of the stomach were not of the dark red colour represented in the above figure, but of a

yellow tint, this being, of course, dependent upon the nature of the food.   The shape of the body, foot, and toes, were all identical with the figure in the Monograph, and its manners completed the picture.   After many rapid flights, twists, and turns, it at length dashed into some flock adhering to a stem, contracted its body into a ball, and kicked itself round and round with great vigour, until weary of watching I dislodged it.   A few other examples occurred from different localities, but it is a rare species.

Habitat—Streams, Co. Wexford; a bog, Co. Waterford; the Canal, Dublin.

Notommata cyrtopus, Gosse.

[The Rotifera, vol. ii. p. 22, Pl. XVII. fig. 7.]

Not frequent.   The two colourless eyes always apparent.   In several examples the *auricles*, of somewhat oblong shape, were freely everted.

Habitat.—Streams, amongst algæ, Cos. Wexford and Carlow.

N.B.—Hitherto the auricles of this species have not been seen, but I fancy their presence was suspected.

Notommata tripus, Ehrenberg.

[The Rotifera, vol. ii. p. 22, Pl. XVII. fig. 4.]

Although the auricles of this species are somewhat larger and more rounded than represented in the figure in the Monograph, they never could be termed "great globose," as described of *N. pilarius*, and the general contour of the body, together with the thick and deeply incised folds at the neck, approach closely to it. It is a quaint little creature, whose upright tail gives it a marked individuality, and a fairly common species, which seems to take the place in this country of its congener *N. pilarius*, which I have not yet seen.   I found one specimen whose brain (?) or eyeball (?) had evidently received some injury, for it hung from the back of the red eye as a grey pear-shaped globe, suspended by the stalk, which wobbled about from side to side when the animal moved. The digestive sac seems simple and undivided; I have seen a rotation of granules throughout the entire chamber.

Habitat.—Pond, bogs, and streams, Co. Wexford.

Notommata forcipata, Ehrenberg.

[The Rotifera, vol. ii. p. 23, Pl. XVIII. fig. 1.]

A dead specimen, from a bog, Co. Wexford.

Notommata brachyota, Ehrenberg.

[The Rotifera, vol. ii. p. 24, Pl. XVII. fig. 1.]

Essentially a scavenger this species has frequently occurred, four or five together, feeding busily within the empty skins of aquatic larvæ and shells of small species of Entomostraca, the very soft pliant nature of the body affording a marked adaptation to the situation.   The very large stomach was always filled with a light brown granulated mass as described in the Monograph.   The red eye was mostly visible, but only when it swam in the open could the minute auricles be detected.

Habitat.—Ponds, bogs, not uncommon, Co. Wexford.

Notommata saccigera, Ehrenberg.

[The Rotifera, vol. ii. p. 24, Pl. XVII. fig. 2.]

So exactly resembling the figure referred to, as it glided along the slide with auricles extended, that I have little doubt of its identity, though I did not get a glimpse of it from any other point of view; the face was kept flat upon the glass as it moved.

Habitat.—A pond, Co. Wexford.

Notommata naias (?), Ehrenberg.

[The Rotifera, vol. ii. p. 25, Pl. XVII. fig. 2.]

About the same size ; the shape of the creature did not correspond with that of the above figure, the head being very much wider than the body, which latter tapered from it to the foot; perhaps the empty state of the stomach may account for this, but the formation of the head seemed identical with it; the clear brain bore a small eye close to its extremity, which looked black by transmitted light, but was of a deep red colour when viewed

with light from above. The foot and toes were exactly as described by Mr. Gosse. A pair of *moderate-sized auricles* were frequently everted.

Habitat.—A single example from a marsh drain, Co. Wexford.

Notommata lacinulata, Ehrenberg.

[The Rotifera, vol. ii. p. 26, Pl. XVII. fig. 9.]

Common everywhere.

Notommata volitans, sp. nov.

[Pl. III. fig. 4.]

Sp. Ch.—Body cylindric, tapering to the foot; head very broad; auricles small, and continually everted; brain clear; toes rather long.

So like *N. lacinulata* in size, general appearance, and manner, gaily flitting about with auricles everted and protruded trophi, it was not until sometime that I recognized its pretension to specific rank. The body tapers abruptly both in width and depth from the very broad head to the tail. The single-jointed foot bears two decurved blade-shaped toes, just double the length of the above-named species.

Abundant.

Habitat.—Ponds and streams, Cos. Wexford and Waterford.

Notommata cylindriformis, sp. nov.

[Pl. III. fig. 5.]

Sp. Ch.—Body cylindric, long, with parallel sides; brain large, dark, and sacculated; toes of moderate length; auricles not observed.

Occurred several times. The dense black brain mass is somewhat similar to that of *N. aurita*, and placed very low down in the neck; but no eye was apparent. The body, always white throughout, is of a narrow oblong shape, internal structure normal, length about $\frac{1}{150}$th of an inch.

Habitat.—Ponds, streams, Co. Wexford.

Notommata larviformis, sp. nov.

[Pl. III. fig. 6.]

Sp. Ch.—Body cylindric, tapering from the head; auricles oblong; foot long, one-jointed; toes minute.

Glistening white. This little creature was on business intent, and so like a young larva that at first I was quite deceived. Having exhausted the resources of its hunting ground, however, it set sail across a tiny lakelet, striking out regularly with the long single-jointed foot, which bore two tiny toes placed close together. The cylindric body tapered finely toward the foot, and from the head there issued, almost on a line with the frontal margin, a pair of oblong auricles. Alighting upon the opposite shore it twisted about with great activity, and was speedily hidden from sight. No eye or brain was visible. Length about $\frac{1}{195}$th of an inch.

Habitat.—A bog, Co. Wexford.

Notommata rubra, sp. nov.

[Pl. III. fig. 7.]

Sp. Ch.—Body long, cylindric, annulate; head narrow, cone-shaped; auricles oblong; brain long, narrow, and coated with black at the extremity; mastax small; toes small, cone-shaped.

This species seems to approach closely both in figure and description to *N. torulosa*, Pl. xxxii. fig. 20, of the Supplement.

The body is a long, narrow cylinder, with many annular constrictions from the neck to the foot, which latter is composed of one broad truncate joint with a depression in the middle, which gives it the appearance of two united bulbs, upon which are placed the small cone-shaped toes. The head tapers to a narrow cone, from the fore-part of which a long clear tubular brain descends far down into the neck, passing over the mastax, which can be seen through it, its rounded end being of an intense bl..ck, not sacculated but as though it had been splashed with deep black ink. The oval mastax was bent toward the ventral surface. I am not certain as to the form of the trophi. A pair of long, narrow auricles were occasion-

ally thrust out from the head close to the frontal margin (*not pedunculated*). A long, narrow stomach extends from behind the mastax close to the base of the short, blunt tail, and is usually well-filled with food of various colours. The ovary is large, spreading over the whole of the ventral floor; a large ovum is generally in process of development. A contractile vesicle of considerable size is situated just above the foot. The whole body of the animal is extremely soft and its movements vermiform; it incessantly wriggles, twists, contracts, expands, and pushes the wormlike head now here, now there. In one instance it contracted the lower half of the body, which fell into innumerable folds, sat down on the little peg-like toes in an erect position, everted the long auricles, and thus remained for a time, then set sail, keeping the body in the same contracted state, and kicking out the foot now and then to aid progression, which was slow.

When grubbing for food along the stem of a weed the lower end of the body is lifted high above the level, and thus held aloft it proceeds upon its way. The colour varies from deep red to the palest rose-pink. Length from about $\frac{1}{90}$ to $\frac{1}{100}$ of an inch.

Habitat.—Frequent among the decaying stems of *Calletrichia verna*, in a pond, Co. Wexford.

Copeus spicatus, Hudson.

[The Rotifera, vol. ii. p. 29, Pl. XVI. fig. 2.]

A very handsome example, whose interior would have furnished a long list of diatoms and desmids of various shapes and colours, notably one like two semi-globular green bodies united by a band, bristling over with prominent acute spines, an awkward customer to swallow, but nothing seems to come amiss to these apparently delicate-skinned creatures; their power of accommodation is extraordinary.

Habitat.—A bog, Co. Wexford.

N.B.—I have seen some indications that the spines of the desmid mentioned above are developed *within* the walls of a transparent gelatinous envelope.

Copeus pachyurus, Gosse.

[The Rotifera, vol. ii. p. 31, Pl. XVI. fig. 4.]

Several of this interesting species occurred from bogs in the Co. Wexford, the sense organs always reduced to mere inconspicuous tubercles, the mastax and trophi of enormous size ; the subglobose saccate tail affords a good feature for identification.

Habitat.—A bog, Co. Wexford.

Copeus caudatus, Collins.

[The Rotifera, vol. ii. p. 33, Pl. XVI. fig. 5.]

A pair of these creatures lay *together* dead ; the foot in both was partially withdrawn. It is strange that my first acquaintance with the species should bear such marked testimony to their peculiar habit of associating in pairs, noticed by Mr. Gosse. They were both females and of the same size.

Habitat.—A pond, Co. Wexford.

Copeus Cerberus, Gosse.

[The Rotifera, vol. ii. p. 34, Pl. XVI. fig. 3.]

This lumpish creature much resembled a maggot. The body was china white, the stomach full of food almost black in hue. The shape of the face was very undefined, the ciliary wave of the disc ever changing in shape and position, the interior surface somewhat protruding beyond it ; there were no apparent auricles, but I could see the circular wave of cilia rotating upon the lateral areas, the eye (?), placed vertically across the origin of the lowest brain was of a black hue, not red, as described by Mr. Gosse. The mastax was small, and the trophi shaded from orange colour into black at the tips. Several of the species occurred.

Habitat.—A bog, Co. Wexford.

Proales decipiens (Ehrenberg).

[The Rotifera, vol. ii. p. 36, Pl. XVIII. fig. 6.]

The annulations of the body and the larva-like motions of this little creature are unmistakable.

Habitat.—Drains and bogs, Co. Wexford.

Proales felis (Ehrenberg).

[The Rotifera, vol. ii. p. 36, Pl. XVIII. fig. 17.]

Two of this curious species occurred from a marsh drain. The bodies were filled with dark green vegetation. The prominent proboscis described in the Rotifera as "a soft lobe of translucent flesh" was well developed. I once caught sight of the large crimson eye as the creature turned.

Habitat.—A marsh drain, Co. Wexford.

Proales gibba (Ehrenberg).

[The Rotifera, vol. ii. p. 37, Pl. XVIII. fig. 8.]

This stout little person was in great trouble, the toes were attached to the stem of *Vaucheria*, and it was making frantic efforts to release itself, but all in vain. It is a rare species; I have only found two examples during six months' research.

Habitat.—A marsh drain, Co. Wexford.

Proales sordida, Gosse.

[The Rotifera, vol. ii. p. 37, Pl. XVIII. fig. 7.]

Agreed in all points with the above figure—rare.
Habitat.—A stream, Co. Waterford; the Canal, Dublin.

Proales tigridia, Gosse.

[The Rotifera, vol. ii. p. 38, Pl. XVIII. fig. 10.]

A single specimen; rare.
Habitat.—A stream, Co. Wexford.

Proales petromyzon (Ehrenberg).

[The Rotifera, vol. ii. p. 38, Pl. XVIII. fig. 9.]
Habitat.—Several from a pond (always free), Co. Wexford.

Proales inflata sp. nov.

[Pl. IV. fig. 1.]

Sp. Ch.—Body stout, short, flask-shaped; foot saccate; trophi small; disc prone; eye large, deep red.

A single dead specimen, bearing some resemblance to *P.*

petromyzon in the position of the coronal disc, which was quite prone, and in the shape of the trophi and the foot; but the head was more distinctly marked out; the body flask-shaped, being broadest at its lower end; the upper portion of the broad stout foot (?) was entirely filled with a large clear contractile vesicle, the foot glands appearing below it. A large, deep crimson eye rested upon the top of the mastax; no further details were recognisable. Length about half that of the above-mentioned species.

Habitat.—A bog, Co. Wexford.

Furcularia forficula, Ehrenberg.

[The Rotifera, vol. ii. p. 41, Pl. XX. fig. 1.]

Both the ordinary and stouter variety of this species are not uncommon, the latter being the more rare; their favourite hunting-ground appears to be the forsaken tubes of small aquatic larvæ, up and down which they vigorously forage for food. I have seen two or three together positively *racing* against each other, and the rapidity with which they turned at the end of the tube was amazing. No doubt these are the mysterious tubes alluded to by Dr. Hudson, of which dozens occur amongst filamentous debris and floccose sediment. In one instance the original occupant was at home, and popping out the little brown head, seized a new species of Rotiferon, which I was endeavouring to sketch, and coolly devoured it wholesale before my eyes, leaving me aghast, pencil in hand ! *En passant,* I have sometimes met with one of these tubes, which is an exceedingly pretty object, being woven out of a blue-green species of *Oscillatoria,* which hung in a long thick fringe from the sides, a deeper shade of colour marking the course of the tube.

Habitat.—Streams and ponds, Cos. Waterford and Wexford; the Canal, Dublin.

Furcularia gracilis, Ehrenberg.

[The Rotifera, vol. ii. p. 42, Pl. XIX. fig. 14 *a*.]

The bulging prominence of the ventral surface towards the foot distinguishes this species from *F. cæca,* which it closely resembles in size and shape.

Habitat.—A stream, Co. Wexford.

Furcularia cæca, Gosse.

[The Rotifera, vol. ii. p. 42, Pl. XX. fig. 4.]
A single example; characteristics not very satisfactory.
Habitat.—A stream, Co. Wexford.

Furcularia gibba, Ehrenberg.

[The Rotifera, vol. ii. p. 43, Pl. XIX. fig. 13.]
Although bearing considerable resemblance to *Diaschiza semi-aperta*, with which it is said to be often confounded, the distinctions are sufficiently obvious. The gibbous area of the body presents none of the angularities of outline noticeable in the latter species. The *toes* also are much shorter, of a stouter make, and their upward curve is more gradual. The eye is situated *almost on* the frontal margin. The trophi are larger and more unsymmetric.
Habitat.—Streams and ponds, Cos. Wexford and Carlow; not unfrequent in Co. Waterford; the Canal, Dublin.

Furcularia ensifera, Gosse.

[The Rotifera, vol. ii. p. 43, Pl. XX. fig. 3.]
The peculiar manner in which the toes are articulated apparently to the trunk, without the intervention of a foot, affords a good feature for recognising the species. I have seen the rounded, pliant, flesh-like toes lapped round each other at the tips in a sort of twist.
Not uncommon.
Habitat.—Streams, bogs, ponds, Cos. Carlow, Kerry, Waterford, and Wexford.

Furcularia marina, Dujardin.

[The Rotifera, vol. ii. p. 44, Pl. XIX. fig. 15.]
Common in tide-pools.
Habitat.—River Barrow, Co. Wexford.

Furcularia Boltoni, Gosse.

[The Rotifera, vol. ii. p. 45, Pl. XX. fig. 2.]
I was fortunate enough to find what I take to be this species in great abundance in a stream running by the " The Mill Post," Co. Waterford. It was, indeed, quite the specialty of the stream. It is recognisable at once by the peculiar formation of the foot, of

which fig. 2 *a*, in the above-mentioned Plate, gives some idea, though not quite correct in detail, which is due to the fact that it was copied from a dead specimen. Of the three joints of which it is composed the two first are long, and of equal length, the second being set on at an open angle, thus giving a ventral direction to the lower portion, in which position it is mostly carried, the first joint being almost wholly withdrawn. The third joint is somewhat shorter than the others, and usually telescoped into the second, the tips of the toes alone appearing beyond it—these latter are quite correct in the figure given in the Monograph. The whole foot is telescopic, and sometimes entirely concealed within the body. When fully extended it is of surprising length, quite equal to the length of the body, and extremely flexible. The foot glands are remarkably conspicuous, their large pear-shaped heads lying within the body, from whence the diminishing tubes descend to the toes. The stomach, surmounted by two clear globose gastric glands, is very large, and when empty appears to be sacculated. The drawing of the head in the above figure is correct. I have never seen it otherwise than truncate on the frontal margin, in the centre of which is the red eye at the anterior end of a very large brain, which descends deeply into the neck. The shape of the body is more oblong than fusiform, and rather flat on the ventral side.

Its manners are those of a typical Furcularian, rapid, restless, voracious. It seems to feed almost exclusively upon a long, rod-like diatom, of an amber colour, with which the stomach is generally distended, or rather extended, for they can be seen lying lengthwise from end to end within. I saw one creature attack a diatom half as long again as itself; it placed itself on a line with it, seized the end, and rammed it down in the most masterly style until it reached the end of the body, then, finding there was still a long piece projecting beyond its head, it reversed the action of the strong incurved forcipate trophi, hauled it all up again, and discarded it as a hopeless case. I have seen an empty frustule discharged, which still retained its shape. I have also seen a long oval egg, bearing a bright red eye at its anterior end, deposited upon the slide. The species is very delicate, and dies rapidly when captured.

Habitat.—A stream among *Cladophora* and *Vaucheria*, Co. Waterford; a single specimen from a stream, Co. Wexford; tide-pools, River Barrow, Co. Wexford; the Canal, Dublin.

N.B.—I noticed that the specimens from tide-pools were smaller than those from streams, and much more quiet and deliberate in manner, and the first and third joints of the foot were not protruded.

Furcularia longiseta (Ehrenberg).

[The Rotifera, vol. ii. p. 46, Pl. XVIII. fig. 16.]

Frequent.

Habitat.—Ponds and ditches, Cos. Waterford and Wexford.

Furcularia æqualis (Ehrenberg).

[The Rotifera, vol. ii. p. 46, Pl. XVIII. fig. 15.]

One specimen occurred which answered to the description of the body; but the toes, though nearly so, were not absolutely of equal length.

Habitat.—A pond, Co. Wexford.

Furcularia sterea, Gosse.

[The Rotifera, p. 25, Pl. XXXI. fig. 15, of "Supplement."]

This species has occurred several times, though not common. It is stout and compactly made, the specific feature being well defined. It was first identified as the above-named species by Mr. C. Rousselet, to whom I had sent it amongst others in a phial. I have met with examples in which no eye was apparent, but usually it is placed in the centre of, and almost directly on the line of, the frontal margin.

Habitat.—Bog-moss, Co. Kerry. A bog, Co. Wexford.

Furcularia semisetifera, sp. nov.

[Pl. IV. fig. 2.]

Sp. Ch.—Sub-cylindric; face oblique; toes long, round, and stout at the base, and abruptly passing at about a third of their length into a hair-like filament.

This species is almost identical with *F. forficula* in shape, size, and in fact all points but the *toes*, but here we find a wide divergence.

Instead of the strong decurved blades of that species with their characteristic notch, these are thick and round at the base with a gap between them, and shortly from their origin they suddenly diminish, and are drawn out into fine hair-like points which describe a gentle curve.   On one occasion these two species happen to be side by side in the same field of view, and the similarity in their appearance and manners was most striking, but the different character of the *toes* was really ludicrous, those of the former so powerful for all purposes, those of the latter so apparently impotent, as though Dame Nature had captiously changed the design midway.   What wonder if the once active creature should at length sink into the drifting existence of *Furcularia longiseta*.

In Plate xxxi. fig. 17, of the "Supplement," there is a figure given showing somewhat the same formation of the toes, but the abrupt elevation of the shoulder in that species and the position of the frontal disc, which is quite prone, proves it to be distinct.

Several from different localities have occurred.

Habitat.—Ponds, ditches, bogs, Co. Wexford.

Furcularia megalocephala, sp. nov.

[Pl. IV. fig. 3.]

Sp. Ch.—Head very large; face oblique; body tapering to the foot; toes long, simple, decurved, and finely pointed.

The most prominent feature of this species is its head; indeed it gives one the idea of being all head, so large is it in proportion to the rest of the body.   It has also a formidable way of drawing down and inverting the middle of the coronal disc as though it intended to devour all before it, recalling to mind pictures of that wondrous Whale of ancient days prepared to swallow up unhappy Jonah. The long forcipate trophi are frequently protruded with a snap; there is a long tubular brain which descends from the fore-part of the head to the fold of the neck.   The foot appears to be but one large joint, the toes long decurved blades finely tapered to a point and without a notch at the base.   The body, which narrowed down suddenly from the head, was pretty—glistening white, the stomach filled with bright green food making a pretty contrast of colour.   Length about $\frac{1}{130}$th of an inch.

Habitat.—Not uncommon in bogs and streams, Co. Wexford.

Furcularia rigida, sp. nov.

[Pl. IV. fig. 4.]

Sp. Ch.—Body arched, very narrow; toes long, pointed, stout at the base, recurved, and rigid.

Bearing some affinity to *F. ensifera*, this species still exhibits some distinctive features. The body is arched, high and very narrow, the back rounded. The face oblique, trophi forcipate. The toes which are round, thick at the base, recurved and pointed, appeared to be quite *rigid* and motionless as it floated about in an aimless manner. Length about $\frac{1}{200}$th of an inch.

Habitat.—A stream, Co. Wexford.

Eosphora aurita (Ehrenberg).

[The Rotifera, vol. ii. p. 47, Pl. XVII. fig. 10.]

Several of these lively little creature occurred among the leaflets of *Utricularia*; their two bright red eyes draw attention at once; and then deeper toward the centre of the body a dark-looking spot is seen which occasionally gives out a flash of red colour as the creature turns; in all cases the body was filled with bright green food, the extremities being remarkably clear and transparent. The head and auricles were also much broader than represented in the figure in the Monograph. I once met with one of unusually large size, I suppose an ancient dame.

Habitat.—Bogs and drains, Co. Wexford.

Eosphora striata, sp. nov.

[Pl. IV. fig. 5.]

Sp. Ch.—Body sub-cylindric, swollen in the middle, hyaline, fluted; head dilate; eyes three; foot long; toes furcate.

A large and conspicuous species, particularly clear white throughout. The dilated head is cushioned within the disc, and truncate on the frontal margin, which bears a bright red eye at each extremity; an ample brain descends to the middle of the neck, and near its end another red eye is placed just above and between two black patches which coat its surface at either side. The lower

half of the brain rests upon an enormous mastax, the square forci-
pate trophi reaching close to the disc.   The body is of oblong shape
slightly swollen in the middle and *deeply* fluted longitudinally,
the circular stomach is situated very low down.   The great
transparency of the tissues rendered all other organs invisible.   The
foot one long and simple joint, the toes two pointed cones, not
quite half its length.   Its manners were quiet, gentle, and deliberate
when feeding, and it swam in the open with an easy gliding motion.
I saw no auricles.   Length about $\frac{1}{95}$th of an inch.

Habitat.—On a submerged leaf of *Comarum* from a bog,
Co. Wexford.

Diglena grandis, Ehrenberg.

[The Rotifera, vol. ii. p. 48, Pl. XIX. fig. 6.]

A splendid specimen amongst the branches of *Cladophora* from
a stream.   It was seated toes apart, and fell about awkwardly from
side to side as though in a dying state.   The contents of the
stomach were of a yellow colour.   The head was constantly in-
verted.   The resemblance to the figure in all points was unmis-
takable.

I found one also among algæ from a stream in the Co. Water-
ford, in whose body I was surprised to see the gleam of many bright
red eyes, but the mystery was almost immediately explained by
the birth of three fully formed individuals in uninterrupted suc-
cession; the first and largest measuring $\frac{1}{230}$ inch in length, includ-
ing the toes.   After the event the parent, much reduced in girth,
swam carelessly away; the babes, I regret to say, drifted under
some vegetation, and when trying to bring them into better view
I must have killed them by over pressure of the cover glass, for
they showed no signs of life.

Habitat.—Streams, Cos. Waterford and Wexford.

Diglena forcipata, Ehrenberg.

[The Rotifera, vol. ii. p. 50, Pl. XIX. fig. 2.]

Not uncommon.

Habitat.—Streams, ponds, Cos. Waterford and Wexford.

Diglena circinator, Gosse.

[The Rotifera, vol. ii. p. 50, Pl. XIX. fig. 4.]

Not common. The peculiar fold at the sides of the neck, seen from the dorsal aspect, was apparent in some, but not in all of them. The gibbous development of the body, and the long narrow neck, together with the widespread crescentic curves of the toes, afford good specific features.

Habitat.—Ponds and bogs, Cos. Waterford and Wexford.

Diglena giraffa, Gosse.

[The Rotifera, vol. ii. p. 51, Pl. XIX. fig. 9.]

I have met with but a single example of this rare species. It was stationary, and lifting the long neck and head high above the level of the body, *craned* it about as though taking stock of its surroundings; both extremities were frequently withdrawn into the tube-like central area of the body in a slow and deliberate manner, then as slowly protruded again.

Habitat.—A stream, Co. Wexford.

Diglena caudata, Ehrenberg.

[The Rotifera, vol. ii. p. 51, Pl. XIX. fig. 8.]

This creature is indeed well described. One might think it had donned a garment at least three times too large for it, which fell into innumerable folds, and greatly impeded all its movements, which were remarkably slow; when swimming in the open, it occasionally gave a little jump forward, and at intervals withdrew the foot and toes *entirely* within the body, just as one would draw in a piston through a tube, then pushed them deliberately out again.

Habitat.—Several occurred from a pool, Co. Wexford.

Diglena permollis, Gosse.

[The Rotifera, vol. ii. p. 52, Pl. XIX. fig. 11.]

Apparently a rare species. I found one within the empty shell of a *Daphnia*; the body was extremely soft and flexible, and

as it twisted about I had much difficulty in getting a good view of its shape. The head was broad on the frontal margin, and sometimes contracted into a straight line, over which the soft proboscis was curled; at times it assumed a conic form and bore little resemblance to the genus to which it belonged. Another appeared swimming in the open, undoubtedly the same species, bearing all the characteristics portrayed in the figure of the Monograph.

From two localities.

Habitat.—A bog, a marsh drain, Co. Wexford.

Diglena catellina, Ehrenberg.

[The Rotifera, vol. ii. p. 53, Pl. XIX. fig. 10.]

A fine stout example, busily rooting amongst a mass of floccose sediment as it stood upon its toes, which were bent forward under the body.

Habitat.—A pond, Co. Wexford.

Diglena inflata, sp. nov.

[Pl. IV. fig. 6.]

Sp. Ch.—Body gibbous in the middle, flat on the ventral surface, white; head long, narrow; no eyes; foot thick, of one or two (?) joints; toes nearly as long as the foot.

The body of this species is white throughout; gibbous in the middle, with a strong fold below the central segment into which the lower portion is continually withdrawn; the long narrow head projects into the usual curved proboscis, the ciliated disc being quite prone and running down nearly the whole length of the neck. The foot, composed of one or two stout joints, bears two short and slightly decurved toes; internal organs normal. Its manners are sluggish; remaining long in the same spot, it twists and turns incessantly. The extremities exhibit great flexibility, while the central area preserves a certain rigidity of form. Size about that of *D. circinator.*

Habitat.—One example from a stream, Co. Waterford; several from a pond, Co. Wexford.

Diglena revolvens, sp. nov.

[Pl. V. fig. 1.]

Sp. Ch.—Body long, sunk in the middle; head arching; hood broad.

The resemblance to *D. mustela*, Pl. xxxiii. fig. 4, of the "Supplement," cannot fail to strike the observer, but there are points of difference which cannot be ignored. The gastric glands, which are very conspicuous, are clear and round, and seated directly at the mouth of the large stomach, not pyriform in shape, or attached to it by long stalks as described of that species; no dorsal antenna was visible; the trophi also differ much in shape, being broad at the top, the semicircular rami curving inward at the tips. The toes, which are always closely adpressed, are nearly three times as long, and the foot glands are remarkably conspicuous. I could see no eyes. Its manners are the very reverse of "fierce and active"; it glided about with great deliberation, the head turned upward, now and then, and slowly revolved upon its long axis with protruded jaws as though in search of floating atoms. Length about $\frac{1}{110}$ of an inch.

Habitat.—Two specimens occurred from a stream, Co. Wexford.

Diglena elongata, sp. nov.

[Pl. V. fig. 2.]

Sp. Ch.—Body long, flat, very flexible, colour white; head long, broadly truncate on frontal margin; proboscis triangular; foot long, narrow, two-jointed; toes short, straight, rod-like, slightly bent at the tips; no eyes.

A very distinct species. Head thick, broad, dilated, with a prominent proboscis overhanging the ciliated face; trophi very long, the semicircular rami much projected, and always gaping; no eyes discernible; body long and unusually flat, of a clear white colour; internal organs normal; foot, two long, rounded, narrow joints, and two straight rod-like toes bent slightly downwards at the tips; the foot glands lie within the body from whence their slender tubes descend to the toes. Its manners are peculiar; it firmly attaches the toes to the slide, stretches out the body to its utmost length, and thus remains for a time with

distended trophi working the cilia of the disc vigorously, then rapidly contracting itself, it again flings out the body as before and the same process is repeated, and so on all round the circle, the toes still adhering to the same spot. Though I watched for a considerable time, I did not once see it either grasp or swallow a single morsel of food. It seems a rare species—only a single example occurred. Length about $\frac{1}{95}$ of an inch.

Habitat.—A bog, Co. Wexford.

Diglena rugosa, sp. nov.

[Pl. V. fig. 3.]

Sp. Ch.—Body cylindric, thick at the head, and tapering to the toes, wrinkled; foot long, thick, cylindric; toes short, broad, pointed, and abruptly decurved.

· This species (if fully grown) is the smallest and most insignificant member of the genus yet discovered, being scarcely half the length of *D. caudatus*, yet it presents some very striking characteristics. The colourless body is cylindric and vermiform, and tapers gradually from the head to the foot. This latter seems not to be marked off by the usual enfolding of the integument, but is a simple prolongation of the trunk, which terminates abruptly in a thick rounded end; the short, broad, and acutely pointed toes are set on near either side, and directed forward. There is a slight indenture in the middle of the back, and from this point the body is *closely wrinkled* down to the toes, and this wrinkled portion is continually shrunk upward with a jerk as though the creature were stung; the upper half is smooth and of firmer consistence; the head is thick and round, the proboscis prominent; the ciliary disc quite ventral in position is continued down to near the middle of the body in a straight line; no eyes were apparent. I could not detect the form of the trophi, if they were present; the stomach is long and narrow, and was filled with a granulated semifluid which rotated rapidly. The contractile vesicle is of a long, narrow, oval shape, and lies upon the ventral floor. Its manners were very erratic; it made sudden darts from place to place, then stopped and twisted about into all sorts of contortions, as though greatly discontented with its surroundings.

Habitat.—A marsh drain, Co. Wexford.

Distemma raptor, Gosse.

[The Rotifera, vol. ii. p. 54, Pl. XIX. fig. 1.]

One fine specimen from a pool which had been formerly exposed to the tide of the river Suir, Co. Waterford.

Distemma platyceps (?), Gosse.

[The Rotifera, Pl. XXXI. fig. 25, of " Supplement."]
[Pl. V. fig. 4.]

Though I could see no eyes, this species seems to correspond closely with the description of the above. The head is very broad, truncate, or even slightly crescentic on the frontal margin, from the centre of which a slender finger-like process was occasionally thrust out, but rapidly retracted again ; besides this, there were one ventral and two lateral projections from the face, somewhat similar to what we find in *D. raptor.* The trophi are large and pear-shaped ; the semicircular rami always held open, and sometimes thrust out with rapid motion to the very hilt, snapped, and withdrawn. Below the mastax, at either side, is a small globose bundle of black granules, presumably the gastric glands. This unusual black-spotted appearance of these organs was notable in the three examples which occurred.

The rest of the body was identical with Mr. Gosse's species, the enormous contractile vesicle forming a very prominent feature.

I give a sketch of the species for comparison with the above-mentioned figure in the " Supplement."

Habitat.—A marsh drain, Co. Wexford.

LORICATE DIVISION.

Mastigocerca scipio, Gosse.

[The Rotifera, vol. ii. p. 61, Pl. XX. fig. 11.]

A dead specimen, among the branches of *Utricularia* from a drain ; also a living specimen from a bog.

Rare. Co. Wexford.

Mastigocerca rattus (Ehrenberg).

[The Rotifera, vol. ii. p. 62, Pl. XX. fig. 9.]

Habitat.—Very common in pond, bog, and stream, Cos. Waterford and Wexford.

Mastigocerca bicornis (Ehrenberg).
[The Rotifera, vol. ii. p. 63, Pl. XX. fig. 5.]

One example only occurred. The toe was longer in proportion to the body than given in the figure of the Monograph, and extremely flexible; it was curled about like the lash of a whip.

Habitat.—A marsh drain, Co. Wexford.

Mastigocerca bicristata (?), Gosse.
[The Rotifera, p. 35, Pl. XXXI. fig. 27, of the " Supplement."]
[Pl. V. fig. 5.]

If the outline of the above-named species is persistent in all details, I am hardly justified in supposing my species to be identical with it, as it differs in two prominent features, firstly, in the curve of the toe, which is of greater length, and sweeps downward continuous with the curve of the dorsal line, not recurved as in the figure given in the " Supplement" (there is also a slender substyle closely adpressed); and, 2ndly, in the termination of the double carinæ, which, instead of ending abruptly at the neck, sweep down along either side of the face, and from between them the ciliary disc is but slightly protruded. The tips of the trophi are not incurved but produced into a long narrow pincer-like form. The general contour of the body approaches closely to that of *M. carinata.*

Habitat.—A marsh drain exposed to high tides of the river Barrow, in which some examples attained to a considerable size : Co. Wexford.

Mastigocerca brachydactyla, sp. nov.
[Pl. VI. fig. 1.]

Sp. Ch.—Body irregularly cone-shaped; head lumpish; toe style-like, short, straight, no substyles, no ridge.

Allied to *M. stylata*, but broadest at the head; body an irregular cone, puckered into constrictions, but not gibbous in the middle ; the toe straight and finely-pointed, only one-fourth the length of the body; no substyles; gait wobbling.

Habitat.—A pond, Co. Wexford.

Rattulus tigris, Müller.

[The Rotifera, vol. ii. p. 65, Pl. XX. fig. 13.]

A rare species. One fine example only occurred among the leaflets of *Utricularia.*

Habitat.—A marsh drain, Co. Wexford.

Rattulus helminthodes, Gosse.

[The Rotifera, vol. ii. p. 65, Pl. XX. fig. 17.]

Not frequent. In the few specimens which occurred the head was always of the same width as the body, but possibly in death there would be a slight contraction, more nearly approaching the figure in "The Rotifera."

Habitat.—A marsh drain, Co. Wexford.

Rattulus cimolius, Gosse.

[The Rotifera, vol. ii. p. 66, Pl. XX. fig. 14.]

One solitary example from a pond. The dark sacculated brain reached almost to the centre of the body. The auricles were occasionally thrust out.

Habitat.—A pond, Co. Wexford.

Cœlopus porcellus, Gosse.

[The Rotifera, vol. ii. p. 67, Pl. XX. fig. 18.]

This is a very common species, and occurs in both still and running waters amongst various aquatic plants and algæ. The absence of styles at the base of the toes and the plump rounded outline of the body render it easy of recognition.

Habitat.—Ponds and streams in the Cos. Waterford and Wexford.

Cœlopus tenuior, Gosse.

[The Rotifera, vol. ii. p. 68, Pl. XX. fig. 19.]

By no means frequent. A few examples occurred.

Habitat.—A bog and a marsh drain, Co. Wexford ; one amongst bog-moss from Co. Kerry.

Cœlopus brachyurus, Gosse.

[The Rotifera, vol. ii. p. 69, Pl. XX. fig. 21.]

This species is noticed as "rare." I have found it in abundance amongst the leaves of *Lemna trisulca* and other small plants, in bogs, drains, and ponds. The very short, plump body, the absence of spinous projections towards the head, and the uninterrupted curving line from the neck to the tip of the strongly-decurved toes defines the species well.

Habitat.—Bogs and drains, Co. Wexford ; a marsh drain, Tramore, Co. Waterford.

Cœlopus cavia, Gosse.

[The Rotifera, vol. ii. p. 69, Pl. XX. fig. 22.]

The short glimpse I had of this queer little creature did not give me an opportunity of naming it with decision, but the gibbous development behind and the position of the toes, which were placed far inward on the ventral surface, lead me to believe that I have named it correctly.

Habitat.—A stream, Co. Waterford.

Cœlopus minutus, Gosse.

[The Rotifera, vol. ii. p. 70, Pl. XX. fig. 20.]

This hump-back species was floating about quite dead, and stretched out to its full length. I could not detect the slender tubes from the head to the stomach mentioned by Mr. Gosse, but instead a tangle of shapeless rods just above it, presumably the *trophi* collapsed by approaching decay ; the toes, two broad decurved blades *exactly* alike in size, seemed to spring from the same point just inside the lorica. They were stretched out in a line with the body, the points diverging so as to form a moderate angle.

Habitat.—A stream, Co. Wexford.

Dinocharis pocillum, Ehrenberg.

[The Rotifera, vol. ii. p. 71, Pl. XI. fig. 1.]

Not uncommon. The long-spurred variety predominates.
Habitat.—Pond and bogs, Cos. Waterford and Wexford.

Dinocharis tetractis, Ehrenberg.

[The Rotifera, vol. ii. p. 72, Pl. XXI. fig. 2.]

This species is rare in comparison to its congener *D. pocillum;* in all cases the spurs were well developed ; the spine between the toes of course being absent.

Habitat.—A bog, Co. Wexford.

Scaridium longicaudum, Ehrenberg.

[The Rotifera, vol. ii. p. 73, Pl. XXI. fig. 5.]

Noticed as "rare," I have met with it in great profusion in bogs. Its movements are quiet and deliberate, the long toes are trailed after it, held close together like a tail ; the large crimson eye certainly appeared to be seated upon the mastax and partook of all its movements. It lives well in captivity, and outlasted all other species in the tank.

Habitat.—Bogs, Co. Wexford.

Stephanops lamellaris, Ehrenberg.

[The Rotifera, vol. ii. p. 75, Pl. XXI. fig. 7.]

Some very fine specimens occurred among waterweed from a marsh drain ; in some instances the three posterior spines of the lorica were projected upward at a considerable angle from the body, which gave it quite a bristled appearance. Can it be that they are raised or lowered at the will of the animal ? The width of the head and the body were always much broader than given in the figure referred to. From the same dip appeared some others resembling *S. muticus*, apparently without the posterior spines, but I had not an opportunity of watching them to ascertain this point to a certainty.

Habitat.—A marsh drain, Co. Wexford ; a cattle-pond, Co. Waterford.

Stephanops unisetatus, Collins.

[The Rotifera, vol. ii. p. 76, Pl. XXI. fig. 8.]

Not frequent.

Habitat.—Ponds and bogs, Cos. Waterford and Wexford.

Diaschiza valga, Gosse.

[The Rotifera, vol. ii. p. 77, Pl. XXII. fig. 12.]

This species is fairly common.   I rely upon the more rounded and tapering form of the toes as the distinguishing feature between it and *D. Hoodii* which it so closely resembles ; the cleft down the back of the lorica is always apparent as it turns round a stem or filament.

Habitat.—Ponds and bogs, Co. Wexford ; a pond, Co. Waterford.

Diaschiza exigua, Gosse.

[The Rotifera, vol. ii. p. 78, Pl. XXII. fig. 13.]

This tiny little creature was grubbing in a small heap of flock and by turns exhibited all sides to me.   Viewed laterally the body was high, the toes much decurved ; viewed dorsally it was very narrow and much pinched in toward the foot ; the head was large in proportion ; I could not detect an eye.   Rare.

Habitat.—A marsh-drain, Co. Wexford.

Diaschiza Hoodii, Gosse.

[The Rotifera, vol. ii. p. 79, Pl. XXII. fig. 15.]

This species is noticed as " rare " by Mr. Gosse.   I have found it in great abundance and of various sizes in all fresh waters ; not unlike *Notommata lacinulata* in general outline it is at once distinguishable by the deep cleft down the back which can be best seen as it creeps round the stems of small plants and algæ ; the body is also much more depressed than that species.   The margins of the lorica behind are most difficult to discern, as they are laid flat upon the body, which protrudes beyond them, thus hiding their outline.

Habitat.—Ponds and streams, Cos. Waterford and Wexford.

Diaschiza pæta, Gosse.

[The Rotifera, vol. ii. p. 79, Pl. XXII. fig. 11.]

Of frequent occurrence. The very large rose-red eye, extending almost wholly across the neck (when seen) denotes the species unmistakably.   The toes, in all examples, were shorter, stouter,

and much less recurved than represented in the figure of the Monograph. The little globular ball noticed by Mr. Gosse was not present, but I have seen it in *Diaschiza semi-aperta*, a mere bubble which floated away.

Habitat.—Amongst algæ in ponds and bogs, Co. Waterford.

Diaschiza semiaperta, Gosse.

[The Rotifera, vol. ii. p. 80, Pl. XXII. fig. 10.]

Not so frequent as the foregoing species. It was only after long and careful watching that I was enabled to satisfy myself of this creature's identity; for, although agreeing in most particulars with the figure and description in the Monograph, the gape at the lower end of the dorsal cleft was not apparent. This I found to be due to the fact that it was *as frequently closed* as open. If a good vertical view be obtained, the strange manner of the creature will show this clearly. These manners are so highly characteristic that I wonder they have not received more definite notice: when feeding it incessantly withdraws the foot with a jerk, throwing back the long pointed toes on either side of the body, at the same time burying the head far back upon the neck within the lorica, thus assuming an almost spherical shape. When in this position the plates of the lorica are drawn apart to their fullest extent, and a wide gap is seen throughout their entire length; then, as the toes are brought down, and the head again protruded, they are drawn together, and the temporary aperture is closed more or less entirely according to the varying undulations of the body. This practice has, I believe, something to do with the digestive process, for it always occurs when the animal is feeding, and is followed by various evolutions of the internal organs.

Habitat.—Bogs, streams, and ponds in Co. Wexford; bog-moss, Co. Kerry; a pond, Co. Waterford.

Salpina mucronata, Ehrenberg.

[The Rotifera, vol. ii. p. 83, Pl. XXII. fig. 1.]

A rare species.

Habitat.—A pond, a marsh-drain, Co. Wexford. In bog-moss, Co. Kerry.

Salpina spinigera, Ehrenberg.

[The Rotifera, vol. ii. p. 84, Pl. XXII. fig. 2.]

A few examples.   The lumbar spine was well-developed.
Habitat.—A pond, Cos. Waterford and Wexford.

Salpina brevispina, Ehrenberg.

[The Rotifera, vol. ii. p. 84, Pl. XXII. fig. 4.]

Very common.   Variable in the length of the body, and also
in the width of the dorsal cleft, which latter depends upon the
internal condition.   The stippled markings of the lorica are best
seen in dead specimens.
Habitat.—A pond, Cos. Waterford and Wexford.

Euchlanis dilatata, Ehrenberg.

[The Rotifera, vol. ii. p. 90, Pl. XXIII. fig. 5.]

Very common.   The parallel lines of the dorsal and ventral
flanges, and the pinched appearance of the dorsal posterior notch,
mark the species at once.   I could detect no seta on the foot.
The large amber-coloured stomach, studded with clear globules, is
ever rolled from side to side with rhythmical precision.
Habitat.—Ponds and streams, Cos. Waterford and Wexford.

Euchlanis macrura, Ehrenberg.

[The Rotifera, vol. ii. p. 91, Pl. XXIII. fig. 6.]

This was a very small specimen, possibly not fully grown.   It
was dying.   The foot was retracted; only half of the toes were
visible beyond the lorica.   My attention was immediately arrested
by the semicircle of very long and coarse cilia revolving at either
side of the head, just at the juncture of the lorica.   The body was
more depressed than than that of *E. dilatata*, the lorica not pinched
in above the foot, but the flanges were almost identical in shape
with that species.

A single specimen among the branchlets of *Vaucheria*.
Habitat.—A stream, Co. Carlow.

Euchlanis triquetra, Ehrenberg.

[The Rotifera, vol. ii. p. 91, Pl. XXIII. fig. 4.]

This splendid species is fairly frequent, the dorsal crest well developed; the glass-like clearness of the lorica, and the creature's gentle, quiet way give ample opportuuity to study the internal structure. The muscular bands at the sides of the body, the lateral canals with their vibratile tags, and the digestive system, are all clearly visible.

Habitat.—Ponds, drains and streams, Co. Wexford; a stream, Co. Waterford.

Euchlanis deflexa, Gosse.

[The Rotifera, vol. ii. p. 92, Pl. XXIV. fig. 1.]

The formation of the head of this species, which is peculiar and differs much from its congeners, gives it a very definite character. But a few examples occurred.

Habitat.—Amongst algæ in a stream; in a pond, Co. Wexford; a stream, Co. Waterford.

Euchlania pyriformis, Gosse.

[The Rotifera, vol. ii. p. 93, Pl. XXIII. fig. 2.]

Very scarce. Of singular beauty, the lateral expansions of the lorica being remarkably thin and clear, and the bend of the upper flanges gives a further expression of their tenuity.

Habitat.—A bog, a stream, Co. Wexford.

Cathypna luna (Ehrenberg).

[The Rotifera, vol. ii. p. 94, Pl. XXIV. fig. 4.]

Common everywhere.

Cathypna rusticula, Gosse.

[The Rotifera, vol. ii. p. 95, Pl. XXIV. fig. 6.]

I have little hesitation in applying this name to the species in question, although the toes are much more slender and somewhat longer than given in the figure referred to. The narrow and simple frontal aperture is identical with it, as is also the shape of

the body, the very transparent lorica, and the rose-pink hue of the large eye; the very conspicuous trophi are of an orange brown colour, slightly tinted with pink from their close proximity to the eye.

Habitat.—Bogs, drains, streams, Cos. Waterford and Wexford.

Distyla flexilis, Gosse.

[The Rotifera, vol. ii. p. 97, Pl. XXIV. fig. 7.]

This species abounded amongst *Confervæ* growing on the sides of a water-tub placed under a pump in the month of September. Earlier in the summer not a single specimen occurred from the same place. The longitudinal flutings of the very flexible lorica were strongly marked; the eye was conspicuous. Its manners were always slow, creeping lazily among the filaments.

Habitat.—Among *Confervæ* in a water-tub, Co. Waterford; a bog, Co. Wexford.

Monostyla lunaris, Ehrenberg.

[The Rotifera, vol. ii. p. 98, Pl. XXV. fig. 2.]

Very common.

Habitat.—In all waters, Cos. Waterford, Carlow, Wexford, and Kerry.

Monostyla cornuta, Ehrenberg.

[The Rotifera, vol. ii. p. 98, Pl. XXV. fig. 1.]

Common. Cos. Wexford, and Waterford.

Monostyla Lordii, Gosse.

[The Rotifera, vol. ii. p. 99, Pl. XXV. fig. 5.]

This is a fairly common species. The coarse tesselation and crumpled appearance of the lorica affords a satisfactory distinction from its congeners, but *invariably* the square excavation behind was lacking, a rounded outline taking its place. This variation of form is noticed by Mr. Gosse, who suggests that it may afford sufficient ground for specific rank.

Habitat.—Ponds and bogs, Co. Wexford; *Vaucheria*, from a stream, Co. Carlow.

Monostyla quadridentata, Ehrenberg.

[The Rotifera, vol. ii. p. 100, Pl. XXV. fig. 3.]

The longitudinal striations of the lorica, and its unusual flexibility, together with the V-shaped gape of the frontal margin, denote the species. I have seen it twice. In the first example, which was dead, the horns were not visible ; in the second, they were partially protruded and finally withdrawn while under observation.

Habitat.—Among *Myriophyllum* in a bog, Co. Wexford.

Colurus deflexus, Ehrenberg.

[The Rotifera, vol. ii. p. 102, Pl. XXVI. fig. 1.]

Several examples of this rare species occurred in bogs and ditches, and in one locality, a deep drain of a marsh by the seaside, it was quite frequent. The rounded excavation behind, the much greater plumpness of the body, and its shaded yellow tint form considerable differences between it and *C. deflegus ;* the ventral cleft seemed always to terminate upon the breast. Its manners were slow and heavy, exactly the reverse of its sprightly relative.

Habitat.—Ponds and ditches, Co. Wexford; a marsh drain Tramore, Co. Waterford ; among the stems of *Vaucheria*, Co. Carlow.

Colurus obtusus, Gosse.

[The Rotifera, vol. ii. p. 103, Pl. XXVI. fig. 3.]

Fairly common.

Habitat.—Ponds and streams, Cos. Waterford, Wexford, and Carlow.

Colurus caudatus, Ehrenberg.

[The Rotifera, vol. ii. p. 104, Pl. XXVI. fig. 6.]

Easily recognized by the long toes, which are frequently thrown apart. Not uncommon.

Habitat.—Ponds, bogs, and streams, Cos. Waterford, Wexford, and Kerry.

Colurus pachypodus,[1] sp. nov.

[Pl. VI. fig. 2.]

Sp. Ch.—Lorica slants in a straight line from above the foot to the middle of the breast; foot very stout, of several bulging joints; toe single, style-like, nearly as long as the foot.

Not unlike *C. caudatus*, when viewed laterally, and of the same size, but the body is deepest in the centre, to which the margin of the lorica sweeps down in a straight line from above the foot. The foot is thick and long, and composed of several bulging joints. The toe is single, style-like, and almost of equal length with the foot. The hood sweeps down in a bold curve to the breast.

Habitat.—A tide-pool, River Barrow, Co. Wexford.

Colurus tesselatus, sp. nov.

[Pl. VI. fig. 3.]

Sp. Ch.—Lorica tesselated, raised at the sutures; no dorsal cleft, but a wide curved excavation behind; ventral cleft gaping; foot stout; toes spread wide apart.

About the same size as *C. obtusus*; the lorica of this pretty little species is coarsely tesselated, no cleft behind, but a wide open curving notch; body deepest toward the head, ventral cleft gaping. The foot is short and stout; the toes, which are almost of equal length with the foot, are always held wide apart. A rare species; four examples occurred.

Habitat.—Bogs, Co. Wexford.

Metopidia lepadella, Ehrenberg.

[The Rotifera, vol. ii. p. 106, Pl. XXV. fig. 6.]
Habitat.—Common everywhere.

Metopidia solidus, Gosse.

[The Rotifera, vol. ii. p. 106, Pl. XXV. fig. 11.]
Very rare, a solitary example.
Habitat.—A stream, Co. Wexford.

---

[1] παχύς, thick; πούς, foot.

Metopidia oxysternum, Gosse.

[The Rotifera, vol. ii. p. 107, Pl. XXV. fig. 8.]

The dorsal ridge was much higher than in the figure quoted above, but the *sternum* was not prominent; very rare, only one example occurred.

Habitat.—A stream, Co. Waterford; a pond, Co. Wexford.

Metopidia triptera, Ehrenberg.

[The Rotifera, vol. ii. p. 108, Pl. XXV. fig. 7.]

This very interesting form is said to be rare. I have found it frequently in all fresh waters.

Habitat.—Ponds, bogs, and streams, Cos. Kerry, Waterford, Wexford.

Metopidia bractea (Ehrenberg).

[The Rotifera, vol. ii. p. 109].

The largest of the genus. Very common. I have never seen the eyes.

Habitat.—In all fresh waters.

Metopidia ovalis (?), Ehrenberg.

[The Rotifera, Pl. XXXIV. fig. 2, of " Supplement."]

This not uncommon species answers very closely to Ehrenberg's figure and description referred to above. It has occurred in several localities. The depressed and oval shape of the lorica, narrowed in front, the dorsal plate truncate at both ends, its margin not excised, are identical, but the frontal excision of the ventral plate is deeply crescent-shaped, not square. The excision behind for the protrusion of the foot is square, not round. The hood is very prominent.

Habitat.—Ponds and pools, Co. Wexford.

Monura colurus, Ehrenberg.

[The Rotifera, vol. ii. p. 109, Pl. XXVI. fig. 7.]

This species is said to be exclusively marine, but I have found it twice in fresh water, among confervoid growth, on an old leaf which had lain in a well; the outstretched hook, the unusual

length of the body from head to foot, the rounded ends of the lorica, both behind and before, and the long, single, style-like toe correspond exactly with the figure above mentioned.

Habitat.—A well, tide-pools, Co. Wexford; a small pond, formerly exposed to the tide, Blenheim, Co. Waterford.

Cochleare turbo, Gosse.

[The Rotifera, vol. ii. p. 111, Pl. XXVI. fig. 10.]

This was evidently a very well grown specimen, the body much more plump and rounded than in the figure referred to, especially over the dorsal area.   I did not perceive it to be " three-sided " but rather of an interrupted rounded outline somewhat flattened on the ventral side.   There were two conspicuous globose gastric glands seated near the mouth of the stomach, a large ovary beneath it; the red eye was placed upon the lower end of a semi-globose brain, The face was oblique and just as described in the Monograph, the two lower half-cones being considerably protruded, which produced a chin-like appearance.   The toes were occasionally divided, but more usually pressed together, and upon their points the creature balanced itself as upon a pivot, and swung about in an aimless manner.

Habitat.—A marsh drain, Co. Wexford.

Pterodina patina, Ehrenberg.

[The Rotifera, vol. ii. p. 112, Pl. XXVI. fig. 11.]

Frequent.   The borders of the dorsal plate widely stippled. *Habitat.*—Ponds, Cos. Waterford and Wexford.

Pterodina valvata, Hudson.

[The Rotifera, vol. ii. p. 113, Pl. XXVI. fig. 13.]

Rather scarce.   Lorica so thin as to be hardly perceptible. *Habitat.*—Ponds, Co. Wexford.

Pterodina clypeata, Ehrenberg.

[The Rotifera, vol. ii. p. 114, Pl. XXVI. fig. 14.]

This species, agreeing closely with the figure given in the Rotifera, is somewhat broader, and not so distinctly truncate behind;

the margins of the frontal aperture both on the dorsal and ventral sides are exactly similar to the figure referred to. The foliaceous expansions reach to the rounded edges of the lorica and there spread upward; they are always of a dark gray-brown hue. I have seen the sides of the lorica bent downward in some instances, and bent acutely upward like a pair of wings at other times, when the progress was much like the flight of a bird on a windy day. It is said to be exclusively marine. I have found it occasionally in bog-waters.

Habitat.—A bog, a marsh drain exposed to tides, Co. Wexford; a cattle-pond, formerly exposed to tides, Blenheim, Co. Waterford.

Brachionus urceolaris, Ehrenberg.

[The Rotifera, vol. ii. p. 118, Pl. XXVII. fig. 6.]

Numbers of this handsome species occurred in the Cos. Waterford and Wexford.

Habitat.—Ponds.

Brachionus rubens (?), Ehrenberg.

[The Rotifera, vol. ii. p. 119, Pl. XXVII. fig. 5.]

With the exception of being much smaller than the foregoing species, the spines on the frontal margin being longer and less bent, the mastax placed more toward the centre of the body, there was little distinction between them.

Habitat.—A pond, Co. Waterford.

Brachionus Bakeri, Ehrenberg.

[The Rotifera, vol. ii. p. 120, Pl. XXVII. fig. 8.]

In this species the spines both before and behind are much more developed than in the figure given in the Monograph, and not only is the lorica facetted, but invariably stippled all over; very handsome and of frequent occurrence.

Habitat.—Ponds, Cos. Waterford and Wexford.

Anuræa serrulata, Ehrenberg.

[The Rotifera, vol. ii. p. 124, Pl. XXIX. fig. 8.]

Common.

Habitat.—Bogs, Co. Wexford.

Anuræa brevispina, var. Gosse.

[The Rotifera, vol. ii. p. 124, Pl. XXIX. fig. 5.]

Common.

Habitat.—In stagnant ponds, Co. Waterford.

Notholca thalassia, Gosse.

[The Rotifera, vol. ii. p. 127, Pl. XXIX. fig. 2.]

Said to be exclusively marine. I have found two specimens among the branchlets of *Vaucheria* in a small cattle pond, at one time exposed to tides from the river Suir. The water was perfectly fresh, the pond being fed from a spring. They were fine healthy specimens. Their manners were deliberate, and they continually revolved upon their transverse axis, head backwards. It has also occurred from a mountain stream, but examples from tidal pools always displayed much greater robustness, and more vigour and rapidity of movement.

Habitat.—A cattle-pond, a tide-pool, Co. Waterford; a stream, a tide-pool, Co. Wexford.

[Pl. VI. fig. 4.]

Three of these singular-looking creatures were attached to the body of a young *Nais*. The head tapers to a sharp beak which was buried in the soft skin of the worm, upon whose juices they apparently feed. So wide a departure from the usual structure of the mouth of a Rotifer raises a doubt whether they may be truly classed among the group to which in other respects they seem to bear close affinity. The body is white, smooth, gibbous in the middle, and, curving downwards, tapers at both extremities. A black brain or eye (?) is placed over the mouth of the stomach, which latter occupies almost the entire cavity of the body, and was filled with a light gray granulated substance. Below it, and close to the foot, is a large clear vesicle, probably the contractile vesicle. The foot, one large bulbose joint, bears two slightly decurved blade-like toes of moderate length. There is no trace of mastax or trophi. The creature was singularly stiff in movement, and the foot was evidently non-retractile. Not measured, but about the size of *Notommata cyrtopus*.

Habitat.—A pond, Co. Wexford, August.

The following additional species were found in the summer of 1892 :—

Notops forcipita, sp. nov.

[Pl. VI. fig 5.]

Sp. Ch.—Body stout ; dorsum rounded, ventral surface flat ; head bent downward ; disc an obtuse cone, ciliary wreath simple ; eyes two ; trophi forcipate ; foot ventral, withdrawn ; toes two.

This species resembles *N. hyptopus* both in general outline and in internal structure, but is of much smaller size and is at once distinguished by the possession of two tiny dark red eyes, which are placed close together in a little socket upon the surface of, and almost in the centre of the disc, which bulges forward ; the great size of the forcipate trophi is also remarkable ; they occupy almost half the entire length of the body, their tips approaching the margin of the disc toward the ventral side.   The head is continually withdrawn into a stiff fold of the integument, which is deeply and widely scolloped on the margin, these gaps being then closed and their edges brought together.   There is a depression at either side of the rounded dorsum from whence the body again bulges out.   The foot is quite ventral in position and nearly always withdrawn ; the toes are moderately long, widest from the vertical aspect, straight, and pointed ; they are invariably directed forward under the body.

Its manners are lively, busily nibbling at everything that comes in its way.   Length from $\frac{1}{236}$ to $\frac{1}{154}$ of an inch.

Habitat.—Several from a bog, Co. Wexford.

Notommata lucens, sp. nov.

[Pl. VI. fig. 6.]

Sp. Ch.—Body cylindric, tapering from a broad head to the foot, hyaline ; foot conspicuous, of one or two joints ; toes slender, pointed, adpressed ; head wide, auricles small ; brain large ; eye conspicuous ; trophi forcipate, very large ; disc prone.

This very attractive species is at once distinguished by the enormous size of the head and trophi, which together measure fully half its entire length, and from behind which the body rapidly diminishes to the foot.   The disc is quite prone, and

descends to a considerable distance on the ventral surface; the broad pale yellow brain descends to, and apparently rests upon the forepart of the mastax, and at its extremity are three or four dark grey round cells, upon which is seated anteriorly a lovely rose-red globate eye. A pair of small round auricles are occasionally everted almost on a line with the frontal margin. The enormous forcipate trophi spring from the middle of the body and are peculiarly weak and slender in proportion to their length. The stomach is long and narrow, reaching close to the foot; no other organs were visible. The foot, composed of one or two (?) joints is conspicuous and rather flat; the toes, a trifle longer than the foot, are slender, pointed, slightly decurved, and habitually adpressed.

Its manners are slow and methodical; it adhered firmly by the toes to a certain spot, and from thence twisted about in all directions, working the cilia vigorously for over an hour; sometimes it lifted the head up, and revolved around, everting the small auricles, then again bent downward. I noticed that the trophi were hardly ever brought into use, and seemed very feeble. In the position of the disc this species closely resembles *N. saccigera*, but the shape and size of the head, the conspicuous foot, and slender tapered and pointed toes, are widely different. Length $\frac{1}{154}$ of an inch.

Habitat.—Amongst *Callitrichia verna*, from a pond, Co. Wexford.

Notommata gigantea, sp. nov.

[Pl. VII. fig. 1.]

Sp. Ch.—Body cylindric, stout; head very small, truncate; no auricles; brain small; eye minute; trophi very small, forcipate; foot saccate; toes minute; stomach enormous; ovary very large; contractile vesicle small, globate; tail conspicuous.

This is one of the largest of the genus I have yet seen. Its form is a stout cylinder, narrowed at either end. The integument, in fully matured examples, of great transparency, and puffed out from the viscera to a considerable distance, thus affording an excellent view of the internal organs, the minutest details of which can be studied with ease. The head is remarkably small, the disc

truncate.   A small but clearly-defined brain depends from the margin, bearing a tiny red eye-speck a little below the middle. The trophi, situated close to the disc, are short, and describe a square outline.   A short fulcrum supports two stout, solid-looking rami, upon which the unci appear to be soldered; the manubria are longer than the fulcrum, and curl inward at the base; their action is slow and deliberate.   From either side of the upper part of the head a tiny granulated bag is suspended by a thread; these may be the salivary glands, but their mode of attachment is peculiar; delicate muscular bands are visible running down close to the body-wall, to which they are fastened at intervals by slender threads.   The vascular system is represented by lateral canals of unequal dimensions, and apparently without tags; they curl inward at about two-thirds distance from the head to the small contractile vesicle, which lies hidden between the stomach and the ovary.   (I found it in a specimen subject to lateral pressure.) From this they seem again to emerge, and run down the centre of the great saccate foot to the toes.   A short œsophagus leads to an enormous sacculated alimentary chamber, of a yellow tint, which extends throughout the whole length of the body, and on its shoulders are seated two large pear-shaped, semi-transparent, and nucleated gastric glands, which are attached by their narrow end to the body-wall.   The ovary is also of enormous size, with three or four ova in an advanced stage of development.   The foot is thick and short, and almost entirely covered above by a clear finger-like tail.   The toes are very minute, sharply pointed, and placed close together in the centre of, and on the lowest level of, the foot.   The foot glands are well developed.

I found numbers of this fine species within the eggs of the water-snails, upon which they feed, in company with *Furcularia micropus* (?), and the eggs and the young of both species in every stage surrounded them.

As may be anticipated from the habitat, its manners are sluggish, ever rolling about and inverting the extremities to the distraction of the student.   I had the good fortune to catch a wanderer between the slide and the cover-glass, which enabled me to study it at leisure.   When the species is only half grown it is hardly recognizable, and looks like a shapeless lump of wrinkled

and sometimes mottled skin, revolving and twisting incessantly. In one of the eggs upon which they were feeding I noticed two small apertures, by which no doubt they had effected an entrance. The length in full-grown individuals varies from $\frac{1}{35}$ to $\frac{1}{50}$ of an inch; the width from $\frac{1}{80}$ to $\frac{1}{115}$ of an inch.

Habitat.—In egg-clusters of water-snails. A pond, Co. Wexford.

Furcularia micropus (?), Gosse.

[The Rotifera, vol. ii. p. 46.]

[Pl. VII. fig. 2.]

Sp. Ch.—Body cylindric, larviform; head truncate; brain ample, with small red eye-speck near the lower end; trophi forcipate, broad; foot broad; toes two, small, cone-shaped.

Owing to its extreme flexibility and unceasing contortions the shape of the creature defies description. It seemed to delight in giving itself temporary waists in impossible places all along the line, and the shape portrayed one moment was wrong the next. The head is not large, and generally truncate on the margin, but sometimes it is projected forward in the middle, and bent down until the disc is almost prone. There is an ample brain, within which is seated a tiny red eye-speck toward the lower end. The trophi are broad and very conspicuous; they are situated rather low in the neck, but are brought to the margin by the retraction of the head when required. The stomach is large, the contents thickly nucleated. The foot is broad, and rather flat, and indistinctly marked off from the body. The foot glands are well developed. The toes—two small cones—are set close together and diverge. I noticed that at the extremities of the frontal margin there was an appearance of auricles, but a closer scrutiny proved it to be delusive. I am not certain that the coronal disc was a complete circle; occasionally it appeared to break off abruptly, and run down in a V-shaped slit on the ventral side. The sketch giving a lateral view, represents the animal in its most habitual attitude when feeding, with sunken neck, and head bent backward. When swimming in open space it shrinks up the body into numberless close-set folds, squares the frontal margin, and loses all trace of its former appearance as it *wags* itself merrily along.

I found numbers of this species and their eggs within the eggs of water-snails, where they ceaselessly wriggled and twisted about, in company with *Notommata gigantea ;* and, notwithstanding some points of difference, I think it may yet prove to be identical with *Furcularia micropus.* The eye-speck, though present in them all, is so small that it might readily be overlooked, and now and then the shape was assumed which is represented in Pl. XIX. fig. 12, in the Monograph. Length variable, from $\frac{1}{115}$ to $\frac{1}{96}$ of an inch.

Habitat.—Within the eggs of water-snails. A pond, Co. Wexford.

Diglena Hudsoni, sp. nov.

[Pl. VII. fig. 3.]

Sp. Ch.—Body cylindric, ventral surface flat, gibbous behind, deeply fluted ; head rather broad ; hood broad ; trophi forcipate ; foot ventral ; toes of moderate length, divergent, blade-shaped ; no eyes.

When I first saw this creature it was sitting up on end ; the head and neck withdrawn into the trunk, and looked so like one of the genus *Rotifer* that I nearly passed it by ; it began to move, however, when I quickly perceived my mistake. The body, which is remarkably soft and flexible, is deeply fluted longitudinally, rises abruptly behind, and falls into many transverse folds and wrinkles as it descends gradually to a flat and attenuated neck. The head, which slightly dilates, is furnished with a *broad hood*, in place of the usual pointed proboscis ; a good-sized brain descends to the neck. No eyes were visible. The forcipate trophi are remarkably small and simple, and placed low in the neck. The integument was so overlaid with a fine sediment that the internal organs could be but dimly seen ; they appeared to be normal. The short foot is quite ventral in position, and habitually withdrawn ; the toes are of moderate length, blade-shaped, pointed, and slightly decurved ; united at the base they spring widely apart, seem to be immovable, and take no part in locomotion. Its manners are most peculiar, sluggish, and vermiform ; it ever makes fruitless efforts to advance by alternate elongation and contraction of the body, and at every movement the whole viscera are forced violently toward the head ; at rare intervals it

G 2

abandons the crawling motion, and glides onward by means of the cilia, then again resumes it; occasionally it sits up on end, sinks the head and neck into the trunk, and relapses into the quiescent state in which I first found it.   The whole animal is of a pale amber-colour.   Length about $\frac{1}{90}$ of an inch, but capable of considerable extension.

Habitat.—Among *Cladophora flavescens*, from a tide-pool, river Barrow, Co. Wexford.

Diglena dromius, sp. nov.

[Pl. VII. fig. 4.]

Sp. Ch.—Body sub-cylindric, long, slender, and slightly gibbous in the middle; neck long; head long, broadest above, with a tapered proboscis projecting in front; trophi forcipate, broad, and short; foot of one or more (?) joints; toes long, slender, straight; brain ample, narrowing to the extremity; no eyes.

This very slender and graceful species is the fleetest of its brethren, and as it glides swiftly and evenly along with head laid flat, the tapered proboscis projected in front, it darts it forth to the right and left with extraordinary rapidity.   The long straight toes are finely pointed, and slightly decurved at the tips.   They are set close together, and are held a little apart, and when the animal turns are flung wide asunder.   A long and well-defined brain depends from the frontal margin; but I could discern no eyes.

Its manners amusingly resemble those of some of the predatory beetles, and when alarmed it dashes into cover and there remains motionless until the fancied danger is past.

Length, including the toes, $\frac{1}{82}$ of an inch.
Habitat.—A pond, Co. Wexford.

Diglena aquila, Gosse.

[The Rotifera.   The Supplement, p. 28, Pl. XXXI., fig. 20.]

In every point similar to the above figure.

There was a bunch of black globules situated over the forepart of the stomach; a large and distinct brain was visible, but no eye.
Habitat.—On a submerged leaf in a pond, Co. Wexford.

Diglena uncinata, Milne.

[The Rotifera. The Supplement, p. 30, Pl. XXXIII., fig. 13.]

In this species the very remarkable longitudinal lines dividing the foot into three equal parts strikes the eye at once, and the thickness of the base of the toes is also unusual. The long styles, projecting from under the front of the hood, were swept apart in a curve to either side by pressure when the head was laid on the slide ; occasionally the head was raised and flung forward with a jerk and a snap of the jaws.

Habitat.—Among *Utricularia.* A marsh drain, Co. Wexford.

EXPLANATION OF PLATES.

PLATE III.

Fig.
1. *Rotifer phaleratus.*
2. *Microcodon robustus.*
2a.　　,,　　　　,,　　side view.
3. *Notops quadrangularis.*
4. *Notommata volitans.*
4a.　　,,　　　　,,　　side view.
5. *Notommata cylindriformis.*
6. *Notommata larviformis.*
7. *Notommata rubra.*
7a.　　,,　　　　,,
7b.　　,,　　　　,,　　side view.

PLATE IV.

Fig.
1. *Proales inflata.*
2. *Furcularia semisetifera.*
2a.　　,,　　　　,,　　side view.
3. *Furcularia megalocephala.*
3a.　　,,　　　　,,　　head, disc drawn down.
3b.　　,,　　　　,,　　　　,,　frontal margin.
4. *Furcularia rigida.*
4a.　　,,　　　　,,　　dorsal view.
5. *Eosphora striata.*
6. *Diglena inflata.*

Plate V.

Fig.
1. *Diglena revolvens.*
1a.   ,,   ,,   side view.
2. *Diglena elongata.*
2a.   ,,   ,,   side view.
3. *Diglena rugosa.*
3a.   ,,   ,,
4. *Distemma platyceps* (?), Gosse.
4a.   ,,   ,,   side view.
5. *Mastigocerca bicristata* (?), Gosse

———

Plate VI.

Fig.
1. *Mastigocerca brachydactyla.*
2. *Colurus pachypodus.*
3. *Colurus tesselatus.*
3a.   ,,   ,,   side view.
4. Unknown.
4a.   ,,   side view.

Additions.

5. *Notops forcipata.*
6. *Notommata lucens.*
6a.   ,,   ,,   side view.

———

Plate VII.

Fig.
1. *Notommata gigantea,* ventral surface, flattened.
1a.   ,,   ,,   side view.
1b.   ,,   ,,   dorsal view showing gastric glands.
2. *Furcularia micropus,* Gosse (?).
2a.   ,,   ,,   side view.
2b.   ,,   ,,   when swimming, with body shrunk up to half
                                    its length.
3. *Diglena Hudsoni.*
4. *Diglena dromius.*
4a.   ,,   ,,   side view.

VII.

ON PITCHSTONE AND ANDESITE FROM TERTIARY DYKES IN DONEGAL. By PROFESSOR W. J. SOLLAS, LL.D., D.Sc., F.R.S.

So far back as 1857 Dr. Haughton communicated to the Geological Society of Dublin[1] an account of some pitchstone dykes, which traverse the granite of Barnesmore Gap, Co. Donegal. Subsequently they were described by Mr. Kilroe of the Geological Survey,[2] who speaks of them as numerous and as graduating from dark bluish grey glossy pitchstone to light pink or flesh-coloured compact felstone. The specimens which furnished the material for Dr. Haughton's investigations, which include a complete chemical analysis, are preserved in the Collection of the Geological Museum of Trinity College, and my attention being attracted by their remarkably fresh appearance, I had thin slices prepared from them, and these when examined under the microscope reveal a singularly close resemblance in structure and mineral composition to the celebrated pitchstones of Arran. Complete justification is thus afforded for the procedure of Sir Archibald Geikie, who has included these dykes of Donegal in his map of the Tertiary Volcanic areas of the British Isles.[3]

Glossy black and vesicular in hand specimens, with occasional phenocrysts of sanidine and quartz, the pitchstone presents under the microscope (fig. 1) a colourless or brownish glassy base crowded with long slender needles of pyroxene, minute stellate crystallites

---

[1] Journal of the Geological Society of Dublin, vol. vii., p. 196.

[2] Memoir to accompany Sheet 24 of H.M. Geological Survey, 1888.

[3] Transactions of the Royal Society of Edinburgh, vol. xxxv., p. 184, 1889.

and dust-like globulites; magnetite occurs in addition, sparingly dispersed in minute grains and octahedra. The pyroxene needles are incomplete hollow prisms, filled with glass; their edges are rarely continuous straight lines, but jagged with projections which frequently develope on each side into secondary prisms, proceeding from the shaft, like the barbs of a feather, and these by continued growth tend to pass into an extended plate. The angle of extinction measured against the length of the primary prisms varies from 27° to 43°. The angle of the prism, owing to the minuteness and incompleteness of the crystals, is difficult to measure, but such observations as I could make suggested that of augite rather than hornblende. The colour is faint green, and there is no dichroism. The glass immediately

Fig. 1.—Pyroxene and stellate crystallites in a glassy base.

surrounding the pyroxene is usually clear and structureless, but at a very little distance away it becomes dark with granules, which under a high magnification are resolved into clusters of stellate crystallites, wonderfully similar to the minute asters of a sponge such as *Astropeplus* or *Thenea*. The rays of these asters vary in number from two to ten or more, and are generally without action on polarized light; when, as in some instances is the case, they are birefringent, extinction is parallel. Sometimes within a cluster of asters is seen a clear central space, and lying in this a comparatively large aster, with secondary raylets;

occasionally the rays develope into minute lozenge-shaped plates. From these bodies we pass downward in size to the almost ultra-microscopic globulites which are isotropic. No crystals that could be mistaken for amphibole occur in any of the slices I have examined. It is in the stellate character of the crystallites that our pitchstone differs from that of Arran, in which the crystallites are represented by tufts of branching plumose microliths.

Specimens are in the Museum taken from the very edge of the dyke, where it came in contact with the surrounding granite. These differ in structure from the rest of the rock; under the microscope they reveal an irregular banded structure due to alternations of layers almost colourless, with others rich in brown glass, and dusty with globulites. The feather-like pyroxene prisms are absent, but their absence is compensated by the excessive development of stellate crystallites which attain a larger size than in the rest of the rock, at the same time remaining isotropic, or rarely appearing feebly birefringent.

Phenocrysts of quartz are present, and curious elongated streaks of colourless glass devoid of crystallites and structureless, save for certain problematic spherical and tubular bodies near the edge, which are colourless or faintly bluish and transparent; around them is an aureole of different refractive index to themselves, and to the surrounding glass, but also colourless and transparent. One of the little spheres gives a black cross between crossed nicols, and it is probable that both spheres and tubes consist of chalcedony. In some cases additional structures are present, such as rhombohedra, apparently of calcite, and long filaments, with an axial row of highly refringent granules, looking very like *Oscillatoria*. It is possible that these lenticular patches or streaks were formed by a splitting of the pitchstone, while in the viscous state, as a consequence of cooling, the prisms being subsequently filled up with glass and other material.

The specific gravity of the central part of the dyke, as determined by a Walker's balance, was found to be 2·41, of the selvedge, 2·42.

Dr. Haughton's published analysis is given in Column I.; that by its side in Column II. is of an Arran pitchstone, by M. P.

Tait; in Column III. also of an Arran pitchstone, by J. H. Player, taken from Teall's " British Petrography," p. 347.

	I.	II.	III.
Silica, . .	64·04	66·03	72·6
Alumina, . .	10·40	12·55	12·4
Ferric oxide, .	9·36	2·75	·7 (FeO, 1·1)
Lime, . .	4·24	2·80	·9
Magnesia, . .	none	2·33	trace
Potash, . .	3·63	4·13	4·7
Soda, . . .	2·91	5·02	1·7
Loss by ignition, . .	5·13	4·30	5·2
	99·71	99·81	99·3
Sp. gr., .	2·41	—	2·34

The absence of magnesia from a rock containing so much pyroxene is remarkable, but not unique; it would seem to indicate an aluminous hedenbergite as the chief pyroxenic molecule, a suggestion supported by the high extinction angles observed under the microscope.

From the analysis, Dr. Haughton calculated a possible mineral composition for the rock as follows:—

Quartz,	.	.	.	7·33
Felspar,	.	.	.	62·55
Stilbite,	.	.	.	29·83
				99·71

It is interesting as illustrating the aid afforded by the microscope in checking calculations from analysis, to point out that in this case, where the mathematical computation takes no account of paste, the microscope proves it to be present in the state of glass as the chief constituent, while in granite, where the equations leave a surplus of material as paste, the microscope shows that paste is altogether absent.

The bulk analysis is insufficient for determining the mineral

composition of the rock; but it may not be uninstructive to express its results by molecular formulæ as follows :—

MOLECULAR COMPOSITION.

			Per cent.
Hedenbergite, 7·5 $(SiO_2)_2$ CaO FeO,	.	.	18
Sanidine, Or_1Ab_1, 8 $\begin{cases}(SiO_2)_6 Al_2O_3 K_2O \\ (SiO_2)_6 Al_2O_3 Na_2O\end{cases}$	.	.	45
Water pyroxene $(SiO_2)_{40} (Al_2O_3)_2 (Fe_2O_3)_2 (H_2O)_{28}$,	.		34
Quartz, ...	.	.	4
Magnetite (not accounted for), .	.	.	—
			101

The glass probably consists chiefly of the sanidine and what we may term water pyroxene molecules.

Had opportunity been afforded it for complete dehydration a considerable quantity of sanidine and quartz in excess of that now present as phenocrysts would have probably crystallized out, and the hypothetical water pyroxene molecules would have broken up, affording free silica, water, and ferro-aluminous pyroxene, which would crystallize together with the hedenbergite molecules as augite.

Dr. Haughton mentions the occurrence of another variety of pitchstone, presenting an " oolitic " appearance, in association with that just described. This is probably spherulitic, but specimens of it are so friable that I have been unable to prepare thin slices.

The Museum Collection contains specimens of another glassy rock, labelled " Barnesmore, from a dyke 9 feet wide in granite." This proves to be a typical augite andesite, with a structure as much hyalopilitic as intersertal. The felspar occurs in long rectangular longitudinal and square transverse sections, frequently twinned once or twice, and containing a core of globulitic glass. The extinction angle ranges from 11° to 30°. Either several varieties of felspar are present, possibly a series extending from oligoclase to labradorite, or more probably the extinctions are obtained in various directions in the zone [001,010]. The pyroxene is a pale green monoclinic variety, with an extinction angle of 40°. It occurs in small, irregular grains, and long, fibrous jointed prisms, approximately square in transverse section (fig. 2). It is frequently penetrated by the felspar, and then

presents a corroded appearance.   Small octahedra, grains, and
plates of magnetite are abundantly scattered amongst the other
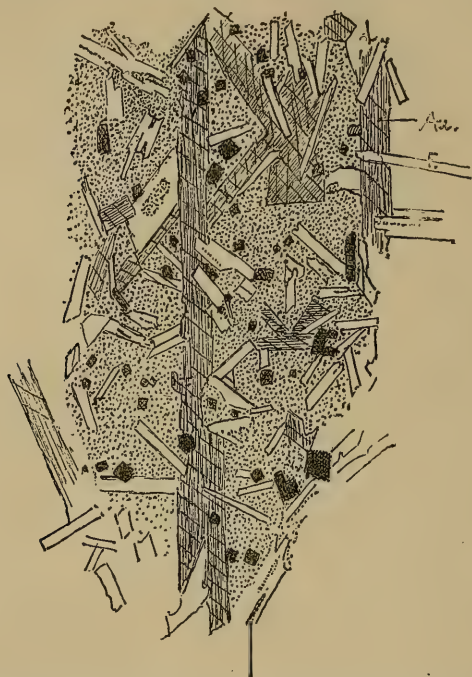
Fig. 2.—Augite Andesite.—The Pyroxene is indicated by close parallel fine lines, the
    Felspar is left white, the Magnetite, cross-hatched, and the Glass dotted (× 225).

constituents.   The colourless glass is rendered brown by included
globulites, and sometimes contains black belonites.

Fig. 3.—Felspar invaded by the
    glassy base (× 187).

Phenocrysts of plagioclase felspar,
fragmentary and often highly corroded,
lie scattered here and there.   One finely
twinned example gave a symmetrical ex-
tinction of 10°, and is probably therefore
oligoclase.   A curious fringe sometimes
extends from the margin of the pheno-
cryst inwards.   This marks the advanc-
ing invasion of the felspar by the glassy
mesostasis; each fibre of the fringe con-
sists of a row of minute granules, resembling globulites (fig. 3).

Numerous more or less spherical inclusions occur, which are evidently infilled vesicles. In some cases these are bordered externally by felspar laths, lying tangentially, an arrangement probably resulting from the expansion of a bubble of steam, driving the glass and included felspar laths before its advancing walls (fig. 4). The infilling material differs in different cases; sometimes it is calcite, sometimes deeply reddish coloured glass, occasionally opal.
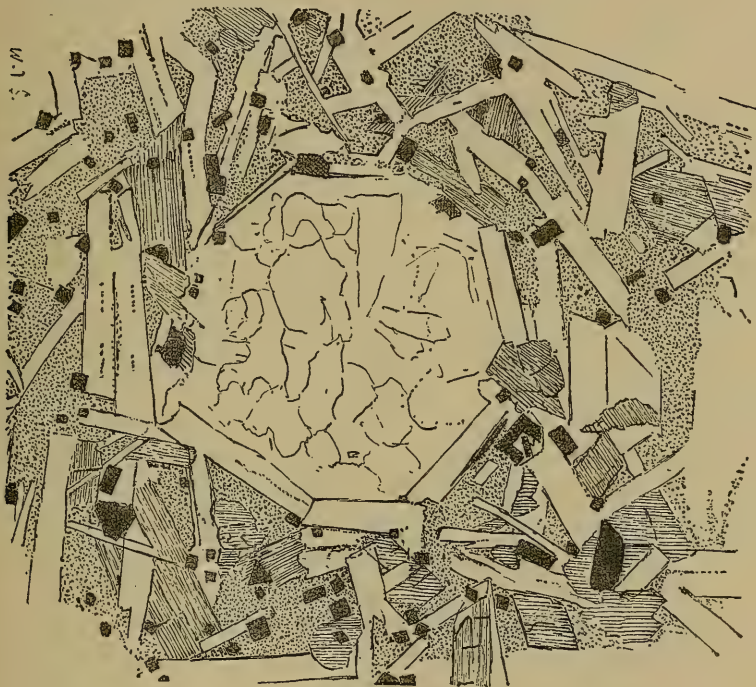
Fig. 4.

The complete absence of even incipient devitrification in these glassy rocks forbids their reference to any earlier date of eruption than the Tertiary; rocks of remarkably fresh appearance are known from much more ancient periods, but these are crystalline —never, so far as I know, truly vitreous.

VIII.

ON THE VARIOLITE AND ASSOCIATED IGNEOUS ROCKS OF ROUNDWOOD, CO. WICKLOW. By PROFESSOR W. J. SOLLAS, LL.D., D.Sc., F.R.S.

IN glassy rocks, consolidating under certain conditions, one of which is a somewhat rapid rate of cooling, a radiate growth of crystals about scattered centres is frequently set up, leading in many cases to the formation of crystalline spheres with a radiate structure. In rocks containing a large proportion of silica, such as rhyolites (obsidian), geologists have long been familiar with this spherulitic structure; but in basic rocks or those poor in silica, such as glassy basalts, its existence has been questioned or denied: and yet under the name of variolite, basic rocks presenting the spherulitic structure in all its details have long been known and frequently described. Their true nature was, however, not at first recognized, and it is only in comparatively recent times that they have received a full and complete explanation. A learned account of the views which have from time to time been held on this subject has been given by Professor Cole and Mr. Gregory,[1] and I need only add to the long list of Papers cited by them one by Dathe,[2] which is of interest as confirming by anticipation some of their views, and another by Lossen,[3] whose remarks, though short, are characteristically to the point. Professor Cole has recently added to our knowledge of this subject by Papers read before this Society,

---

[1] "On the Variolitic Rocks of Mont Genèvre," by G. A. J. Cole and J. W. Gregory, Quart. Journ. Geol. Soc., vol. xlvi., p. 295 (1890); and "On the Variolitic Diabase of the Fichtelgebirge," by J. W. Gregory, *ib.* vol. xlvii., p. 45 (1891).

[2] "Dathe, Beiträge z. Kenntniss der Diabase-mandelstaine," J. B. d. K. Preussichen geologischen Landesanstalt u. Bergakademie, p. 410 (1884).

[3] Lossen, Geologische u. Petrographische Beitrage z. Kembriss des Harzes, *ib.*, p. 7 (1881).

one on the variolite of Cerriggwladys, where it was discovered by
Professor Blake, and this closely resembles that which we are
about to describe ; and another on a Tertiary example from
Annalong, county Down.[1] I am glad to be able to add to the
list a second Irish variolite possessing the essential characters
of the variolite of the Durance. It occurs at Tougher or Round-
wood, near Dublin, where I found it while on an expedition with
Professor Cole.

The variolite of Roundwood forms part of an igneous complex,
which includes diabase, spilite, and consolidated volcanic tuff.
The complex is exposed in a series of isolated hummocks, rising
from peaty and marshy ground on each side of the road from
Roundwood to Annamoe and Glendalough. The first hummock is
met with half-a-mile south of the Roman Catholic chapel of
Roundwood, and the series extends a little over half-a-mile in a
more or less southerly direction, with a breadth of about 300
yards. Although not represented on the published map of the
Geological Survey, this interesting patch of igneous rocks was
evidently not unknown to the surveyor. So long ago as 1848
Professor Oldham[2] called attention to it "as a small boss of
Serpentine," for which rock the strikingly green diabase might
without microscopical analysis be very well mistaken. Mr.
Kinahan subsequently alluded to it as ophite, and with the typical
ophite of the Pyrenees it has as much in common as any ophitic
diabase necessarily must ; but beyond a general resemblance there
seems to be no sufficient justification for the name. Specimens of
the diabase had evidently come under the observation of Jukes,[3]
who with the true petrographical instinct which distinguished him
was contented to name them greenstone. It appears further that
it is only by some oversight that this area does not appear on the
published map. Mr. Watts has kindly allowed me to inspect the
6-inch map on which the surveyor's work is recorded, and there it
is plotted carefully enough, with the remark that it should be

[1] "The Variolite of Annalong," Co. Down, Sci. Proc. Roy. Dublin Soc. (N.S.), vol.
vii. p. 115 (1892).

[2] Oldham, "Notice of the Occurrence of a Small Boss of Serpentine in the County
Wicklow," Journ. Geol. Soc. Dublin, vol. iv., p. 202.

[3] Jukes, Catalogue of the Collection of the Geological Survey of Ireland, p. 14.

inserted on the 1-inch map. This is only one instance out of many of the rather careless way in which the reductions from the 6-inch map have been effected.

It is probable that this is not the only locality in Leinster where variolites are to be found. Thus, DuNoyer[1] speaks of greenstone near Enniscorthy as weathering "into small rough pimples," and Jukes sagaciously remarks that "this would probably be the variolite of Continental authors." On the coast of Waterford, also in Bonmahon Bay, diabase "mandelstein" occurs in association with rocks which I have reason to believe are variolitic.

The greenstone which lies on the right-hand side of the road going from Roundwood, not far from the church of Raheen, is a holocrystalline ophitic diabase, having a specific gravity of from 2·78 to 3·0. The lower value is exceptional; the mean is 2·97. It is of medium grain, the crystals of plagioclase, felspar, and pyroxene, which are its chief constituents, frequently attaining a length of 7 mm. as seen in thin slices. Plates of altered ilmenite, which are not uncommon, sometimes measure as much as 3 mm. across.

The felspar affects long, more or less rectangular outlines, is frequently twinned on the albite—sometimes on the Carlsbad plan, and extinguishes at large angles pointing to labradorite and bytownite. The pyroxene occurs in colourless sections with well-developed cleavage; it extinguishes at from 32° to 45°, and is frequently rendered ophitic by included felspar. Of olivine there is no certain trace, but it is by no means impossible that it was originally present. If in its fresh state the rock was an ophitic dolerite, it has since its extension suffered so much mineral change that its pristine character can only be recognized with difficulty. It has yielded both to the weather and to earth pressure, but of pressure the effect has been small compared to that of the weather. Thus, as shown in fig. 1, the augite has been nearly all converted into chlorite, which has eaten into it along numerous irregular cracks, and extending from them has produced a groundwork of chlorite, in which only small isolated fragments of the original mineral remain. These, which still preserve a common

---

[1] Memoirs of the Geological Survey, 167, 168, 178, and 179, p. 13 (1865).

optical orientation, are probably not always of their original composition, their want of colour suggesting the loss of some ferric constituent.

The felspar has also suffered greatly ; chlorite has everywhere invaded it, often forming within it a coarse irregular network which, in general form, sometimes reminds one of that taken by included glass, so as to suggest the original presence of this material. Calcite is not infrequently developed in it; and epidote

Fig. 1.—Au. augite, Ch. chlorite, F. felspar, Il. ilmenite.

abounds, sometimes penetrating and traversing the felspar, sometimes included within it, sometimes bordering its margins, and frequently forming mosaics, when it does not seem to be specially related to one constituent of the rock more than another. In thin

slices the epidote is pale greenish-yellow, with only faint traces of dichroism : it is to this constituent that the rock, as a whole, chiefly owes its strikingly green colour.

The ilmenite has undergone complete conversion into leucoxene, so that as a rule skeleton plates of leucoxene, often hexagonal in form, and penetrated by felspar, are all that remain to mark its previous presence.

The effects of pressure are seen in the occasional fracturing of the felspar and augite.

The hummocks on the right-hand side of the road consist of a dark brownish-red felsitic-looking rock, with a platy or splintery fracture, in this and in its colour closely resembling some of the Cambrian slates of the district; indeed, in the case of the more thoroughly cleaved examples, some doubt may well be felt as to their true nature on first making their acquaintance in the field, a doubt that a glance through the microscope at a thin slice will immediately dispel. In places, spheroidal jointing is seen in the hummocks, the concentric planes of division being crossed by a second set of fissures running radially. Here and there minute vesicles and amygdaloids appear, and at one spot included fragments of calcite ; one of these, a rounded block of completely crystalline pinkish-red limestone, measures 6 inches in diameter, and is very unlike a segregation or concretionary product ; it looks far more like a derived fragment, caught up by the ascending lava from some underlying stratum. The specific gravity ranges from 2·834 to 3·004 ; the mean obtained from six specimens is 2·91.

The most coarsely crystallized example of these rocks I have met with happens to be somewhat vesicular, irregular cavities some half-an-inch in diameter, now filled in with calcite, occurring abundantly dispersed through it. In this, as in all the rocks on the right-hand side of the road, the chief mineral constituent is felspar, which occurs in lath-shaped crystals, twinned once or twice, generally grouped, as many as six or eight together in stellate clusters. The ends of the crystals are frequently forked and the sides sometimes ragged ; a thread of opaque white material, representing decomposed glass, usually runs through them axially. The same opaque white material occurs between the crystals, and is sometimes distributed in groups of short parallel

lines, which appear to proceed from the side of a felspar lath, diverging from it at angles of about 60°. It thus suggests the reedy form of augite with feathered edges seen in some glassy rocks, but no connexion with augite can now be traced, if any ever existed. The felspar laths are often bent, partly as a consequence of earth pressure, by which they have also frequently been broken across, partly by trichitic growth. Angles of extinction have been measured exceeding 20°; the species is therefore probably andesine. Augite appears to have been originally present in small grains, situated in the interstices left between the felspar; it is now entirely converted into pale-green chlorite. Epidote is thickly scattered in small crystals through the rock, and calcite, which has replaced much of the felspar, is similarly dispersed. Calcite also fills up the cavities of the vesicles, which, though sometimes more or less oval in outline, are more frequently of quite irregular shape, bridged across by threads of rock, or invaded by promontories. Felspar laths sometimes project into them, forming with their surrounding film of altered glass tent-like eminences. The infilling calcite occurs as a mosaic; its cleavage planes are sometimes curved or otherwise distorted; in some cases it presents a fan-shaped radiate structure, but this does not appear to be original, for distorted cleavage planes of earlier calcite grains can be traced across the rays of the fans, which would thus appear to result from the action of pressure on a once existing mosaic : further illustration of the action of pressure is afforded by lines of typical cataclastic granulation, which cross some of the calcite mosaics, in precisely the same fashion as the familiar crush lines in quartz mosaics of granite.

From this rock, with its intersertal structure and slight traces of original glass, up to the completely variolitic modifications, there is every stage of transition, affording a complete passage from the variolites "du Drac" to those "de la Durance." The prevalent rock of the area does not differ in general character from the foregoing, but a greater tendency is observable on the part of the felspar to long curvilinear growths in sheafy aggregates, and in some cases this becomes so clearly expressed that the structure of the rock might properly be described as diffusely spherulitic. The examples in which this is best displayed are very much broken rocks, cracks now filled with calcite traverse them in all directions,

H 2

naturally suggestive of a rapid rate of cooling in the outpoured
lava.

Phenocrysts, much corroded at the time of effusion by the
surrounding glass, are also met with, frequently collected together
in groups. They now consist of chlorite and other secondary
minerals, but were originally composed, in some cases at least, of
olivine.

The slaty character of the rock results from a kind of " auswei-
chungs-clivage." In hand specimens the rock is seen to be tra-
versed by numerous irregularly curved planes of cleavage, which
are usually coated with chlorite and more or less regularly
striated. In thin slices, cut transversely to the cleavage, numerous
undulating dark lines running in a general direction are seen to
divide the slice into lenticular areas. These lines correspond to
the cleavage planes, and that gliding has taken place along them
is shown very clearly in one instance where a crystal of felspar
happening to lie transverse to the cleavage planes has been
repeatedly broken and displaced along them (fig. 2). How slight
the dislocation has been may be judged from the figure; measure-
ments give a maximum displacement for each shear of 0·06 m.m.,
and a total displacement of twice this (0·12 mm.). The two ends
of the crystal have scarcely moved relatively to each other, the
greatest displacement being reached in the middle of the crystal.
On the other hand, the number of glide-planes is very great. The
length of this single crystal (1·2 mm.) is crossed by no less than
eight planes, so that the mean distance between them is 0·14 mm.
The cleavage thus has evidently been produced by a great number
of internal shears, each of very trifling amount, and, as our crystal
of felspar shows, the sum total of the whole, reckoning displace-
ments in one direction as negative and in the other as positive,
might amount to zero. The whole appearance points to packing
under earth-pressure. Save for the presence of minute pheno-
crysts the prevalent rock on the right-hand side of the road
strongly reminds us of the "Spilite" of Rosenbusch.

Near the little cottage opposite the lane leading to Raheen
church variolitic streaks appear in the rock running more or less
parallel to concentric lines of jointing. They are rendered very
distinct by the green colour which many of them present, due to
a copious development of epidote. The varioles are seen in hand

specimens as little rounded bodies ranging in size from that of a pea downwards (Mr. Watts has since found examples half-an-inch in diameter); they are sometimes red, but more usually green in colour and weather to an opaque white powder. Under the
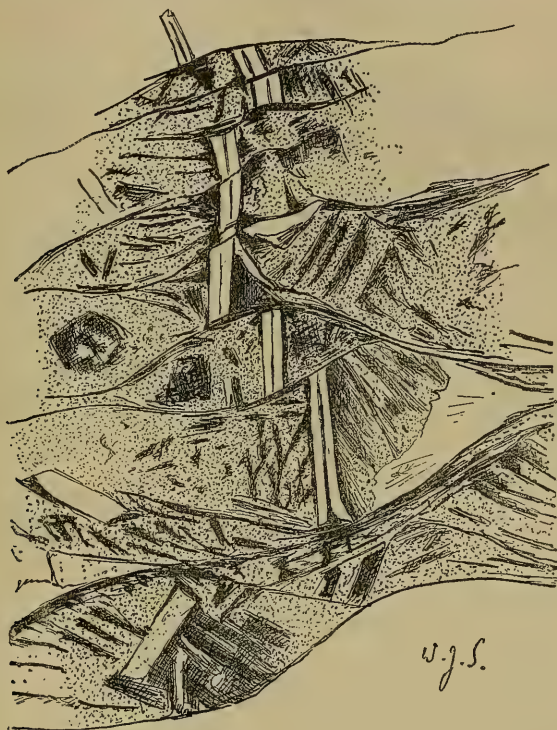
Fig. 2.

microscope the streaked appearance of the rock is seen to be due to irregularly alternating bands of different colour and composition. Some are clearly divitrified glass traversed by numerous wavy lines of opaque white material giving it a fluxional appearance; others are similar, but in addition crowded with spherulites, singly and in groups, while others again are wholly spherulitic, the spherules in this case being more or less devoid of well-defined edges (fig. 3). Superposed upon these structures are crystals of epidote and zoisite collected in bands; these have been developed without completely destroying the structure of the glass, so that

the fine linear opaque streaks, which seem to be fluidal in origin, run through them undisturbed; the structure of the spherulites has also, in some cases, survived epidotization. The varioles not only become confluent, but in some cases a larger entirely includes a smaller one. The structure of the varioles is rendered very obvious by the presence of opaque white or brown material similar
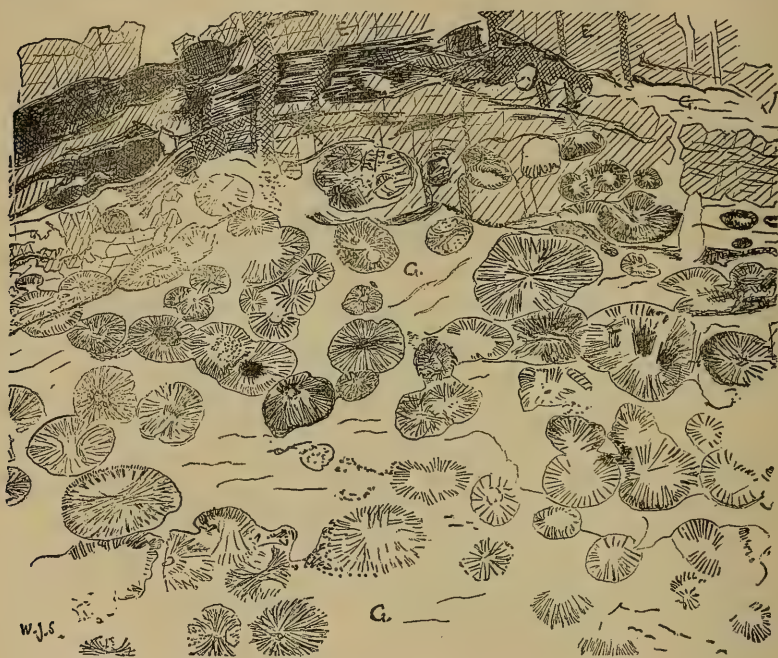
Fig. 3.—Variolitic structure. G. altered glass, E. Epidote, crossed by cracks filled with calcite (chris-crossed). Magnified about 12 diameters.[1]

to that previously alluded to as occurring in the axis of the felspar crystals of the spilite. This borders the rays of felspar, which now chiefly constitute the variole, so that their course may be traced without the aid of polarized light (fig. 4); occasionally, however, it is developed to superabundance, and only serves to obscure: the same material occurs as a definite border about the periphery of the varioles; sometimes it is replaced by a brown translucent substance, which appears illuminated between crossed

---

[1] The slices from which these drawings were made have been mislaid, and it is impossible therefore in all cases to state the amount of magnification.

nicols, and somewhat resembles leucoxene. Frequently it occurs as long black threads strongly suggestive of trichites.

Fig. 4.

In a great number of cases the nucleus of the variole is furnished by a lath-shaped crystal of felspar; from the ends of this delicate rays, also of felspar, repeatedly branching diverge in regular curves towards the margin, leaving at the sides of the nucleus a

Fig. 5.—Sheaf structure for spherulite. Ch. chlorite.

space where but little structure is apparent. When fully developed the whole appearance of this beautiful growth forcibly recalls the distribution of lines of force about a bar magnet (figs. 4

and 5). Scales of hexagonal outline giving parallel-sided transverse sections, and often of a pale green tint, are thickly disseminated through the varioles and the surrounding matrix; many are, no doubt, chlorite, but some, judging from the brilliancy of their colours, between crossed nicols, are probably secondary muscovite. No definite pseudomorphs after augite are to be seen, but it is quite possible that this mineral was originally present, and is now represented by decomposition products such as the scattered chlorite. In the larger varioles a distinction into a central clearer region and an outer more granular zone is of

FIG. 6.—Confluent varioles with central area and outer zone, the darkly shaded portion indicates the opaque border. E. epidote, Ch. chlorite (× 19).

frequent occurrence (fig. 6). The outer zone retains the structure and general appearance of the substance of the smaller varioles; the central portion which polarizes in more brilliant colours is poorer in the radiating opaque lines, representing altered glass, and suggests the previous existence of a cavity, which has been since obliterated by a growth inwards from the outer zone that originally formed its walls. But as opposed to this explanation is the apparent existence of traces of a nuclear felspar-lath in some of these central regions, leading one rather to regard the whole

variole as centrifugal in its growth from its earliest origin, and careful examination leads me to conclude that this view is correct, and that in this instance the central clearer space which polarizes in more lively tints than the rest of the variole, has been produced by subsequent decomposition, and develop-ment of silica. That bubbles were pre-sent (fig. 7), which might have afforded a surface from which growth could take place both inwards into their cavity and upwards into the surrounding glass, is proved by the occurrence of spheri-cal vesicles, now occupied by chlorite and epidote, within the varioles. But these have been without influence on

Fig. 7.—A vesicle filled in with chlorite (Ch.) and epidote (E.).

the variolitic growth. The occurrence of minute phenocrysts, originally consisting of olivine, has already been alluded to in describing the spilite; it is not, therefore, surprising to find them within the varioles, where they usually occupy an eccentric posi-
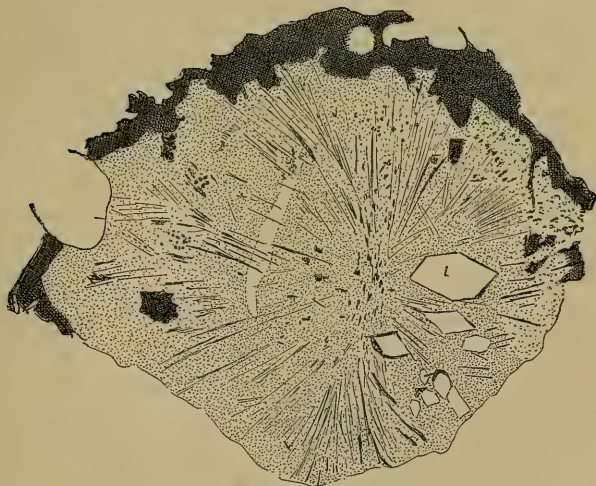
Fig. 8.—Variole, including minute pseudomorphs after olivine, and traversed by a fissure of retreat.

tion, rarely forming the centre and serving as a nucleus. They now consist of chlorite, sometimes with the addition of epidote and calcite (fig. 8).

Transverse or tangential cracks, the "fissures of retreat," of Fonqué and Lévy, are of frequent occurrence in the varioles; in some cases they are traversed not only by the fibres of chloritized felspar, but by the opaque threads which we have regarded as representing decomposed glass (fig. 8). This adds a fresh difficulty in the way of their explanation; it would appear that their formation occurred while the glass was still viscid. Sometimes they are completely infilled with calcite, which in some cases has extended outwards from them in long prisms into the surrounding substance of the variole (fig. 9.)

A chemical analysis was made of the variolitic rock from portions presenting a prevalent reddish colour, and another from portions mainly green. The following are the results:—

Chemical Analysis of Variolite from Roundwood.

	Red variety.	Green variety.
SiO_2,	42·52	37·97
TiO_2,	·892	·92
Al_2O_3,	18·10	19·45
Fe_2O_3,	7·50	7·85
FeO,	4·12	2·95
CaO,	6·07	18·25
MgO,	8·55	4·58
K_2O,	·56	trace.
Na_2O,	4·33	2·90
H_2O,	6·86	2·71
CO_2,	trace	2·58
	99·50	100·16
Sp. gr.,	2·94	3·01

The water was determined by loss on ignition. A qualitative examination of the green variety showed the presence of a considerable quantity of manganese and chromium. The average specific gravity of the variolite is 3·05.

It is scarcely probable that these analyses make any close approach to the original composition of the rock; and in our uncertainty as to the precise nature of many of the products of decomposition, particularly of the chloritic minerals and the white opaque granular material, we cannot attempt any calculation of its

existing mineral composition. It is clear, however, that the original material was of a very basic character. Disregarding the water, the existing rock contains material which would furnish the following :

						Molecules.
Ilmenite,	.	.	.	.	.	1
Magnetite (and Chromite),			.	.	2
Olivine ($Mg_7Fe_1Si_4$),	.	.	.	.	4 (of M_2SiO_4)
Anorthite,	.	.	.	.	.	2
Albite,	.	.	.	.	.	2

FIG. 9.—Part of a variole, showing calcite extending into its substance from a fissure of retreat.

This would give us the sum total of molecules $(SiO_2)_{24}$, $(Al_2O_3)_6$, (Fe_2O_3), FeO, $(CaO)_4$, $(MgO)_7$, $(Na_2O)_4$, a very close approximation to the result obtained by analysis, the water, as subsequently acquired, being disregarded. Since, however, silica has certainly been removed in solution, we must add sufficient of this to convert some of the olivine, and probably some of the magnetite also, into augite, which was evidently an original constituent of the rock. Probably some of the calcium also was present in the form of pyroxene.

By subsequent hydration, and exchange of material, the anorthite has been converted into epidote and zoisite, and the olivine into chlorite; calcite also has been produced probably by the weathering of the anorthite and of the wollastonite molecules in the augite. In connexion with these subsequent changes stand the development of cracks in the highly epidotised portions of the rock and the migration of chlorite from its place of origin to surrounding minerals. No doubt the cracks associated with epidotisation are best developed in those portions of the rock which were originally in a glassy state, and which might consequently have been expected to undergo considerable contraction in the course of devitrification; but at the same time it is clear that where they are most strikingly displayed, the cracks have been produced after the formation of epidote, since single cracks may be traced passing continuously through several crystals of this mineral. A slice in which this is conspicuously shown, consisting chiefly of epidote, resembles a diagrammatic section of a country traversed by mineral veins. The fissures, some of which completely cross the slice, vary in breadth in different parts of their course, branch, and reunite, forming "horses," receive feeders and give off droppers, die out and are replaced by fresh ones running in the same direction. They are now filled with crystalline calcite. It might be conjectured that under the earth-pressure which has produced "ausweichungs-clivage" in the spilite, the hard and resistant epidote became fractured in the direction of the pressure; but even so the cracks are so wide and numerous as to suggest a previously existing want of compactness; and this one would naturally expect to result from the shrinking which it would seem must necessarily occur when anorthite gives rise to epidote. If, for simplicity, zoisite, instead of epidote, be compared with anorthite as regards its molecular volume, we obtain the following :—

	Anorthite.	Wollastonite.[1]	Zoisite.	
	$3(CaAl_2Si_2O_8)$	$+ SiO_3Ca + H_2O$	$= H_2Ca_4Al_6Si_6O_{26}$	$+ SiO_2$
Molecular weight,[2]	810	116	884	60

[1] By wollastonite is to be understood the calcium silicate molecule of pyroxene.

[2] The atomic weight of aluminium is taken as 27 in this and subsequent calculations.

Anorthite (sp. gr. 2·7[1]), $\dfrac{·810}{2·7} = 300$ (molecular volume).

Zoisite (sp. gr. 3·3), $\dfrac{884}{3·3} = 268.$

Wollastonite (sp. gr. 2·8), $\dfrac{116}{2·8} = 41.$

Silica (sp. gr. 2·65), $\dfrac{60}{2·65} = 23.$

Thus the contraction which anorthite undergoes in passing into zoisite amounts to 10·6 per cent., and the result is similar if epidote be substituted for zoisite, while if the united volume of the anorthite and wollastonite molecules on one side of the equation be compared with that of zoisite and quartz on the other, the contraction will be found to reach 14·3 per cent. Possibly the strong tendency to idiomorphic outlines displayed by epidote and zoisite is connected with this contraction in volume. The formation of chloritic minerals, on the other hand, is attended on the whole with expansion of volume. In investigating this complex group we may adopt Tschermak's theory of their constitution, which in any case has the merit of conveniently expressing the facts. From this point of view the members of the chlorite family may be regarded as forming a series, having serpentine at one end, and a hypothetical mineral, amesite, at the other, the intermediate members consisting of mixtures or combinations of these two simplest terms in various proportions, as shown in the following table :—

Molecular Proportions.			Simplest Formula.			
Sp_{10},	.	.	$Si_2O_9Mg_3H_4$,	.	.	Serpentine.
Sp_6At_4,	.	.	$Si_8O_{45}Al_4Mg_{13}H_{20}$,	}	.	Pennine.
Sp_5At_5,	.	.	$Si_3O_{18}Al_2Mg_5H_8$,	}	.	Clinochlore.
Sp_4At_6,	.	.	$Si_7O_{45}Al_6Mg_{12}H_{20}$,	}	.	Prochlorite.
Sp_3At_7,	.	.	$Si_{13}O_{90}Al_{14}Mg_{23}H_{40}$,	}	.	Corundophilite.
Sp_2At_8,	.	.	$Si_6O_{45}Al_8Mg_{11}H_{20}$,	}	.	
At_{10},	.	.	$SiO_9Al_2Mg_2H_4$,	.	.	Amesite.

The constitution of amesite may be expressed by the formula:—

$$Si[\,OAl(OH)_2\,](OAlO)(OMgOH)_2.$$

An actually existing mineral, with a composition closely approaching that of the hypothetical amesite, is a chlorite from Chester,

---

[1] If the specific gravity be taken as 2.75, the molecular volume will become 293.

U.S., to which the formula Sp_9At has been assigned; if this be expanded to express approximately the results actually afforded by its analysis we have:—$Si_{11}O_{90}Al_{18}Mg_{15}Fe_6H_{40}$. The molecular weight is 2970, and the specific gravity 2·71; the molecular volume is therefore 1096, or dividing by 10 (since there are 10 molecules in the group), 109·6, which is almost identical with that of serpentine. For the molecular weight of serpentine is 276, the specific gravity 2·5, and the molecular volume consequently 110. In view of this, and the fact that 9 out of the 10 molecules in the compound consist of serpentine, it would seem that not much error can arise if we assign to the hypothetical amesite a molecular volume of 110.

There are at least two sources from which serpentine is derived, enstatite and olivine. The reaction in the case of the latter may be thus represented:—

$$\underset{\text{Olivine.}}{2Si(O_2Mg)_2} + 2OH_2 = \underset{\text{Serpentine.}}{Si_2(O_2Mg)_3(OH)_4} + MgO.$$
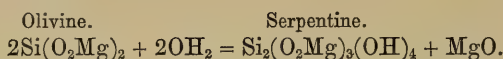
The molecular weight of the olivine is 280, and its specific gravity 3·3; its molecular volume is therefore 85, while that of serpentine is 110. Thus disregarding the single molecule of magnesia on the right-hand side of the equation, the conversion of olivine into serpentine is accompanied by an increase of volume amounting to nearly 30 per cent.

In the hydration of enstatite we have:—

$$\underset{\text{Enstatite.}}{3\,SiOMgO_2} + 2\,OH_2 = \underset{\text{Serpentine.}}{Si_2\,(O_2Mg)_3\,(OH)_4} + SiO_2.$$
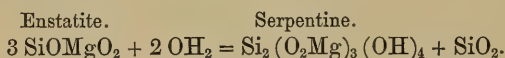
The molecular weight of the enstatite is 300, and its specific gravity 3·1; hence the molecular volume is 96·8, and the increase of volume in passing into serpentine amounts to 13·6 per cent. Had the liberated silica been taken into account, the increase would have been found to be much more considerable, and in a rock consisting of olivine and enstatite it would make itself evident, since the magnesia liberated from the olivine and the silica from the enstatite might be expected to unite to form a further quantity of serpentine. Such a case is represented thus:—

	Olivine.		Enstatite.		Serpentine.
Molecules,	12	+	6	=	9
Volume,	510	+	193·6	=	990

or 703·6 volumes of olivine and enstatite give rise to 990 volumes of serpentine, an increase of 40 per cent. The extrusion of serpentine from altered olivine into cracks in the surrounding minerals and the larger fissures of the whole rock becomes thus readily intelligible.

Turning now to the amesite molecule we perceive that its derivation from pyroxenic material involves great destruction of the pyroxene, as is shown in the following :—

$$\text{Pyroxene.} \qquad\qquad \text{Amesite.}$$
$$[\text{SiO}(\text{O}_2\text{Mg})]_2\text{Si}_3\text{O}_3(\text{O}_3\text{Al})_2 + 2\,\text{OH}_2 = \text{Si}(\text{OMgOH})_2[\text{OAl}(\text{OH})_2](\text{OAlO})$$
$$+ 4\,\text{SiO}_2.$$
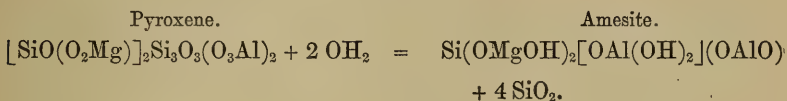
The molecular weight of the pyroxene in the equation is 482 ; and if the specific gravity be taken as 3·25, a very probable estimate, we arrive at 150 for the value of the molecular volume. Since the molecular volume of the resulting amesite is 110, we have here a loss of 40 volumes or 26·7 per cent. If, however, the volume of liberated silica be included in the account, the loss becomes a gain ; we cannot assign a less volume to this than 90, and consequently on the total transaction there will be an expansion of 150 volumes to 200, or a gain of 33·3 per cent.

Since amesite, so far as we know, is never the sole chloritic product of the hydration of pyroxene, it will be more instructive to consider examples in which both serpentine and amesite molecules are produced together ; thus the volume of pennine (Sp_3At_2) is 6·78 per cent. less than that of the pyroxene which furnishes it, and of clinochlore (SpAt) 10 per cent. I must confess to having felt some little surprise at this result, since the general diffusion of chlorite in diabase and other hydrated basic rocks would naturally have led one to expect the chlorite to possess a larger volume than the pyroxene from which it is derived ; but though this is clearly not the case, there is evidently great expansion when the total change involving the liberation of silica is considered. If the volume of clinochlore and quartz be compared with that of the pyroxene from which they result, a total expansion of 34 per cent. will be found ; and since the clinochlore may be assumed to be at least as soluble as the silica, we may suppose that the surplus volume (34 per cent), which is carried away in solution, will

include both these products. Further, the destruction of pyroxene in weathering frequently involves the conversion of the wollastonite molecules into calcite, and this produces great increase in volume; thus :—

<div align="center">

Wollastonite.   Calcite.

$$CaSiO_3 + CO_2 = CaCO_3 + SiO_2$$

</div>

Molecular volume,   . $\dfrac{116}{2\cdot8} = 41$ $\dfrac{110}{2\cdot71} = 40$ $\dfrac{60}{2\cdot65} = 22.$
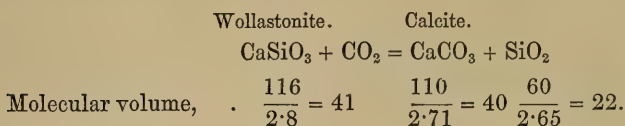
The calcium carbonate is almost of the same volume as the wollastonite, but the total change is an expansion of about 51 per cent.

It may be of interest to consider the total change of volume of a rock consisting of anorthite and augite, when completely altered by the weather. For this purpose we will assume a mixture in which the silica is equally divided between the two minerals, and we will select a pyroxene having the composition found by Teall[1] for this mineral, as it occurs in the Great Whin Sill, while the anorthite may be taken as ideally pure. We shall thus have :—

Pyroxene, ... $Ca_{19}Mg_{21}Fe''_{14}Al_6Fe'''_2Si_{66}O_{198}.$

Anorthite,   .   .   . $11\,(Ca_3Al_6Si_6O_{24}).$

    11 Anorthite + 11 Wollastonite[2] = 11 Zoisite + 11 Quartz
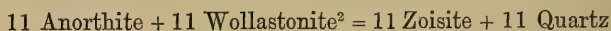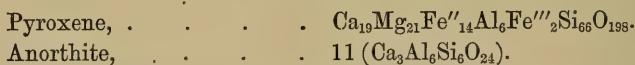
Mol. vol., 300×11 41×11 268×11 $22\cdot5 \times 11$

    Change in volume,   .   .   . $3195 - 3751 = -556.$

     $8\text{ Wollastonite} + 8\text{ }CO_2 = 8\text{ Calcite} + 8\text{ }SiO_2.$
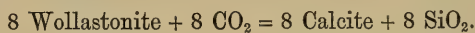
       41×8 40×8 $22\cdot5 \times 8$

    Change in volume,   .   .   . $500 - 328 = 172.$

     Residual Pyroxene.   Pennine.

    $Mg_{21}Fe''_{14}Al_6Fe'''_2Si_{47}O_{141}$ = Sp_9At_4 + $16\,SiO_2$
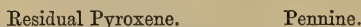
       $32\cdot3 \times 47 = 1518$ 110×13 $225 \times 16 = 360.$

    Change in volume,   .   .   . $1790 - 1518 = 272.$

The total change is thus $444 - 556 = -112$, or a contraction of 112 on a total volume of 5597, i.e. 2 per cent. It is thus evident that when epidotisation is a prevailing change in the weathering of basic rocks the total alteration of volume will not be large, and

---

[1] Teall, "British Petrography," 1888, p. 157.

[2] Calcium pyroxene molecules.

slight difference in the proportions of the minerals constituting the rock may determine whether, on the whole, an expansion or a contraction shall take place. The presence of a small quantity of olivine in the mixture we have assumed would, of course, tend towards expansion. If only as much olivine be added as contains 6 molecules of silica, of which already 132 molecules are present in the mixture, the contraction will become a slight expansion, thus:

$$\text{Pyroxene.} \qquad \text{Olivine.} \qquad \text{Pennine.}$$
$$Mg_{21}Fe''_{14}Al_6Fe'''_2Si_{47}O_{141} + Mg_{12}Si_6O_{24} = Sp_{13}At_4 + 14\ SiO_2$$
$$1518 \qquad\qquad 42 \cdot 5 \times 6 \quad 110 \times 17 \quad 22 \cdot 5 \times 14$$
$$\text{Change in volume,} \quad . \quad . \quad . \quad 2185 - 1779 = 412.$$
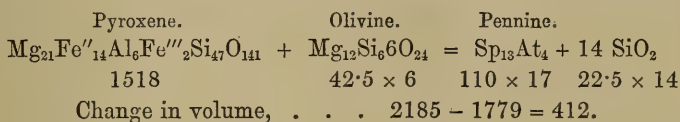
In the previous case when no olivine was present the expansion for pyroxene was found to be 272. This deducted from 412, the expansion now found, leaves 140, by which we must increase the previous result, which we found to be a total contraction of 112, thus: $140 - 112 = 28$, so that on the total change we have now a gain of 28 or 0·4 per cent.

The conversion of anorthite into kaolin and calcium carbonate would bring about a very marked expansion; thus:—

$$\text{Anorthite.} \qquad\qquad\qquad \text{Kaolin.}$$
$$Ca_3Al_6Si_6O_{24} + 3CO_2 + 6H_2O = 3H_4Al_2Si_2O_9 + 3CaCO_3.$$
$$\text{Mol. vol.,} \qquad 300. \qquad\qquad\qquad 300. \qquad 120.$$
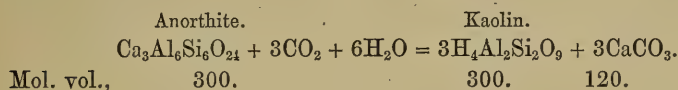
Thus while the epidotisation of anorthite is accompanied by a contraction of about 14 per cent.; its kaolinisation, on the contrary, is accompanied by an expansion of 40 per cent.[1] If, in the mixture we have just considered, we suppose kaolinisation instead of epidotisation to occur, we obtain the following:—

$$11\ \text{Anorthite} \ = \ 33\ \text{Kaolin} \ + \ 33\ \text{Calcite.}$$
$$3300 \qquad\qquad 3300 \qquad\qquad 1320.$$
$$\text{Change of volume,} \quad . \quad . \quad . \quad 4620 - 3300 = 1320.$$

$$19\ \text{Wollastonite} \ = \ 19\ \text{Calcite} \ + \ 19\ SiO_2.$$
$$779 \qquad\qquad 760 \qquad\qquad 427.$$
$$\text{Change of volume,} \quad . \quad . \quad . \quad 1187 - 779 = 408.$$

$$47\ \text{Pyroxene} + 6\ \text{Olivine} = 17\ \text{Pennine} + 14\ SiO_2.$$
$$1518 \qquad 255 \qquad 1870 \qquad 315.$$
$$\text{Change of volume,} \quad . \quad . \quad . \quad 2185 - 1773 = 412.$$

---
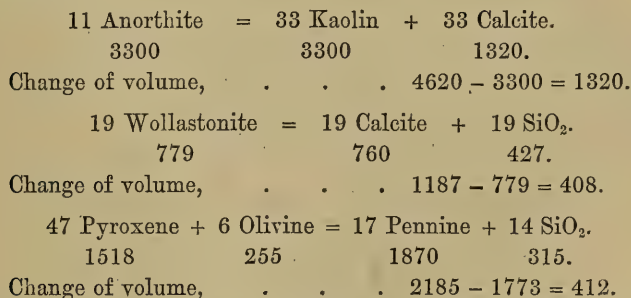
[1] Possibly in this will be found an explanation of the variety of complete kaolinisation of anorthite.

The total change is now a gain of 2140 volumes on 5852, equivalent to 36·4 per cent.

Since anorthite will rarely be converted into epidote alone, but will usually give rise also to kaolin, it is probable that, on the whole, the bulk of the material resulting from the weathering of a basic rock will considerably exceed that which it possesses in the unaltered state.

No one can have examined the slates and other rocks of the Cambrian and Ordovician systems in Leinster and elsewhere, without being impressed with the frequency of the association of chlorite with quartz in the infiltrated veins so common in these rocks. This finds an easy explanation in the simultaneous liberation of chlorite and silica during the weathering of rocks containing pyroxene; and such rocks are of the commonest occurrence in the districts traversed by the chloritic quartz veins.

Before concluding the long digression which our observations on the fissured condition of the epidotised rock have suggested, it may be worth while to inquire into the volume-change accompanying the conversion of orthoclase into muscovite and kaolin. Muscovite may be supposed to arise by the following reaction :—

$$\text{Orthoclase.} \qquad \text{Muscovite.}$$
$$3\ Al_2K_2Si_6O_{16} = Al_6K_2H_4Si_6O_{24} + K_2CO_3 + 12\ SiO_2.$$

Mol. vol., $\quad 3 \times 218 \qquad 274 \qquad 2 \times 62 \quad 22\text{·}5 \times 12.$
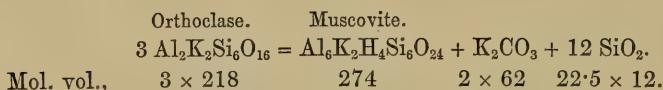
The change in volume is $668 - 658 = 10.$

Thus, on the whole, there is practically no change in volume; but, if the muscovite be considered alone, there is a condensation of 658 to 274 volumes. Unless, therefore, some of the free silica be deposited as quartz along with the muscovite, we should expect to find the development of the last-named mineral accompanied by marked signs of shrinkage in the orthoclase.

The conversion into kaolin is as follows:—

$$\text{Orthoclase.} \qquad \text{Kaolin.}$$
$$Al_2K_2Si_6O_{16} = H_4Al_2Si_2O_9 + K_2CO_3 + 4\ SiO_2.$$

Mol. vol., $\qquad 218 \qquad\quad 100 \qquad 62 \qquad 90.$
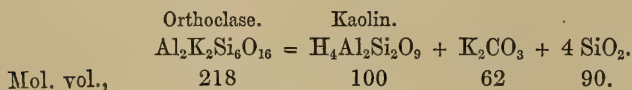
The change in volume is $252 - 218 = 34.$

The expansion, on the whole, is slightly larger than in the

case of muscovite, but the condensation, when kaolin alone is compared with orthoclase, is scarcely less striking. 218 volumes of orthoclase are represented by 100 of kaolin. The porous character of kaolin pseudomorphs, after felspar, is, however, a familiar fact.

When the transformation of minerals is effected under pressure, as in dynamo-metamorphism, we should naturally expect those whose development is accompanied by contraction to be formed in preference to those in which it is accompanied by expansion; and it is possible that the excessive development of epidote in the igneous rocks of Roundwood stands connected with the earth-pressure, to which they have more than once been subjected.

It only remains to mention the tuff, which is now a red slate with typical " ausweichungs-clivage "; it contains pieces of altered glass, fragments of felspar crystals, and patches and veins of chlorite. Since it occurs in company with variolitic and vesicular lava, one may fairly infer that the igneous rocks of Roundwood are situated not far from the actual site of a volcanic vent, which was in activity in Ordovician times, discharging steam and fragmentary materials from its crater, with occasional overflows of lava. The close proximity of a somewhat coarsely crystalline diabase, once an ophitic dolerite, can scarcely be a matter of accident, and one is led to suppose that in it we have a somewhat deeper-seated representative of the extruded spilite and variolite.

IX.

DESCRIPTION OF SOME NEW SPECIES OF ACTINIARIA FROM TORRES STRAITS. By PROFESSOR A. C. HADDON AND ALICE M. SHACKLETON, B.A.

Circumstances have delayed, and will further delay, the completion of the second part of our Report on the Actiniaria of Torres Straits. This being the case, we think it advisable to put on record a description of those new species which we have already determined. We hope to present our completed and illustrated memoir in about a year's time.

The following is a Table of all the species we have as yet identified in the collection made by one of us. The order in which they are here placed must be regarded as provisional, as we are by no means satisfied with any published classification of the Actiniaria.

ACTINIARIA.

I. Edwardsiæ.   (No specimens collected.)
II. Ceriantheæ.
    Cerianthidæ.

        Cerianthus nobilis, n. sp.

III. Zoantheæ.
    Zoanthidæ.
      Macrocneminæ.
          Parazoanthus Howesii, H. & S.; **P. Kochii**, H. & S.; **P. cœsia** (?), (Dana).
      Brachycneminæ.
          Gemmaria Macmurrichi, H. & S.; **G. Mutuki**, H. & S.
          Isaurus asymmetricus, H. & S.
          Zoanthus Coppingeri, H. & S.; **Z. Jukesii**, H. & S.; **Z. Macgillivrayi**, H. & S.

ERRATUM.

For last eleven lines from bottom of p. 116 *read* the following :—

III. ZOANTHEÆ.

        Zoanthidæ.

           Macrocneminæ.

                Parazoanthus dichroicus, H. & S. ; **P. Douglasi,** H. & S.

           Brachycneminæ.

                Palythoa Howesii, H. & S. ; **P. Kochii,** H. & S. ; **P. cœsia** (?), Dana.

                Gemmaria Macmurrichi, H. & S. ; **G. Mutuki,** H. & S.

                Isaurus asymmetricus, H. & S.

                Zoanthus Coppingeri, H. & S. ; **Z. Jukesii,** H. & S. ; **Z. Macgillivrayi,** H. & S.

IV. HEXACTINIÆ.

  A. Stichodactylinæ.

    Corynactidæ.

      Corynactis hoplites, n. sp.

    Discosomidæ.

      Discosoma Kenti, n. sp. ; **D. Malu**, n. sp. ;
        D. macrodactylum, n. sp.

    Rhodactidæ.

      Rhodactis bryoides, n. sp.

    Phymanthidæ.

      Phymanthus simplex, n. sp. ; **P. muscosus**,
        n. sp.

    Cryptodendridæ.

      Cryptodendrum adhæsivum, Klunz.

  B. Thalassianthinæ.

    Thalassianthidæ.

      Actineria dendrophora, n. sp.

      Actinodendron alcyonoideum, Q. & G. ; **A.
        arboreum**, Q. & G.

  C. Minyadinæ.

    Minyadidæ.

      Minyas torpedo (?), Bell.

  D. Actininæ.

    Actiniidæ (Antheadæ).

      Condylactis Gelam, n. sp.; **C. Ramsayi**, n. sp.;
        C. aspera, n. sp.

      Anemonia citrina, n. sp. ; **Kwoiam**, n. sp.

      Actinioides Dixoniana, n. sp. ; **A. Sesere**,
        n. sp.

      Viatrix cincta, n. sp.

    Bunodidæ.

      Alicia rhadina, n. sp.

    Sagartidæ.

      Phellia (?) **sipunculoides**, n. sp. ; **P.** (?) **Devisi**,
        n. sp.

      Paraphellia Hunti, n. sp. ; **P. lineata**, n. sp.

      Thoe (?) **Milmani**, n. sp.

      Adamsia miriam, n. sp.

CERIANTHEÆ.

CERIANTHIDÆ.

Cerianthus nobilis, n. sp.

Form.—Body of great size; presence of a terminal pore not determined; marginal tentacles long, tapering, in three cycles, from about 160 to 170 in number; oral tentacles very numerous.

Colour.—Upper portion of column deep brown, paler below; marginal tentacles, deep flesh colour; oral tentacles, yellowish skin colour. Disc with radial brown lines.

Dimensions.—Length of column probably about 300 mm. (in alcohol 105 mm.); diameter, 26 mm. (in alcohol 19 mm.); length of marginal tentacles, about 80 mm.; length of tube, about 300 mm. (12 inches).

Habitat.—Partially imbedded in the mud on the fringing reef of Thursday Island.

HEXACTINIÆ.

Stichodactylinæ.

CORYNACTIDÆ.

Corynactis hoplites, n. sp.

Form.—Column about twice as high as broad, smooth, pedal disc expanded; tentacles, capitate, of two kinds, (1) marginal and (2) centripetal, situated on the disc, the latter in at least two cycles; mouth can be extended into a short tube, finely ridged internally.

Colour.—Colour, varied; (*a*) column, burnt sienna-colour, with dark paired marks at the top of the scapus; tentacles, translucent white, with a pink or white core at the swollen tip; mouth-cone, speckled gray; throat, orange; (*b*) similar, with pinkish-brown tips to tentacles; six pairs of marks on capitulum; (*c*) transparent grass-green, with brown streaks; tentacles, transparent, green tips.

Dimensions.—Diameter of column, about 8 mm.; height, about 14 mm.

Habitat.—Between Orman's Reef and " The Brothers Island," 6–7 fms., August 18, 1888; also on fringing-reef, Mabuiag, October, 1888.

The various species of Corynactis are difficult to differentiate from each other, so far as the descriptions hitherto published are concerned. This species differs from the type species *C. viridis*, Allm., in possessing a well-marked, diffuse, endodermal sphincter muscle, as well as in other characters which we will particularize in our detailed paper. The specific name is derived from the batteries of large nematocysts in the tentacles.

DISCOSOMIDÆ.

DISCÓSOMA.

We place the three following species provisionally under this genus, as they appear to constitute a regular series; but we feel sure that ultimately the genus will require revision, as the type species *D. nummiforme*, Leuck., appears to differ considerably from other species which are commonly associated with it.

Discosoma Kenti, n. sp.

Form.—A very large Actinian; column narrower below than above; oral disc of considerably greater diameter than column, and thrown into well-marked lobes; tentacles very numerous, subulate, in continuous, rapid, irregular, waving movement; mouth, usually with two gonidial grooves.

Colour.—Various; column, usually gray, passing into buff above, or brownish and rusty orange above, upper portion with pale or sometimes dull violet suckers; tentacles, ashy grey with a green tip, or cindery-brown, sometimes the tentacles have a pinkish lilac tip.

Dimensions.—Diameter of corona, over 300 mm. (a foot or more.

Habitat.—On reefs in Torres Straits.

We have the pleasure of naming this fine species in honour of W. Saville Kent, Esq., who has recently done such good scientific and economic work in connexion with the fisheries of Torres Straits and elsewhere round the Australian coasts.

Discosoma Malu, n. sp.

Form.—Column, soft, massive; upper portion with large suckers, to which pieces of shell often adhere; a slight but distinct crenulated parapet; oral disc of much greater diameter than column, and thrown into folds; mouth round, with two well-marked gonidial grooves; tentacles very numerous, contractile, may be reduced to mere filaments — those of the outermost row in two cycles, large, and of the same size; the centripetal tentacles appear to arise anywhere on the disc, they usually occur in short radial rows, of these the tentacle situated nearest to the mouth is the largest.

Colour.—Whole body pale creamy yellow; the tentacles shade off into pink, and have rosy-red tips.

Dimensions.—Column about 100 mm. high; about 750 mm. in diameter; diameter of corona, over 160 mm.; length of tentacles, 11 mm.

Habitat.—(Of single specimen) surface of reef, Mer, February 14, 1889.

We name this species after the hero Malu, about whom there is a legend which evidently embodies the traditional history of the origin of a portion at least of the ancient initiation ceremonies of Mer. (Cf. "Legends from Torres Straits," Folk-lore i. 1890, p. 181.)

Discosoma macrodactylum, n. sp.

Form.—Salver-shaped, owing to the great expansion of the oral disc, with numerous large suckers on upper portion of column; the long and very contractile tentacles are placed in well-marked linear series, their tips are perforated; mouth with two gonidial grooves.

Colour.—Column, olive-brown, darker above, with pale spots on upper portion; disc, pinkish gray, peripherally passing into pale olive green, which shades into olive brown round the mouth; œsophagus, delicate pink; tentacles, dove-gray, with a yellowish sheen, which is most marked at the tip.

Dimensions.—Diameter of disc, 250–300 mm. or more; mouth, 25 mm. × 57 mm.; tentacles, 40 mm. or more in length.

Habitat.—(Of single specimen) surface of reef, Mer, January 18, 1889.

At first sight this species has very much the appearance of an *Anemonia;* the specific name refers to the long tentacles.

RHODACTIDÆ.

Rhodactis bryoides, n. sp.

Form.—Body, salver-shaped, with a well-marked crenulated parapet; oral disc expanded, of even contour, concave with prominent oral cone; mouth rounded, stomatodæum with twenty-four furrows, but no gonidial grooves; one or two short, knob-like tentacles on most of the crenulations of the parapet, but the bulk of the tentacles are compound, and are grouped in numerous radial lines, twelve of which run up the oral cone; there is an annular clear space between these centripetal and the peripheral tentacles.

Colour.—Column, buff, grayish-brown or cinder colour; disc burnt-sienna colour; tentacles various shades of bluish-green, some on the disc are brown.

Dimensions.—Diameter of disc, 32 mm.

Habitat.—Surface of reefs, Murray Islands.

This species can readily be distinguished from the only hitherto described species of *R. rhodostoma* (Ehr.) and *R. Sancti-Thomæ* (Duch. et Mich). The specific name is derived from its mossy appearance.

PHYMANTHIDÆ.

Phymanthus simplex, n. sp.

Form.—Column, soft, corrugated when contracted; suckers on lower portion increasing in size from below upwards; crenulated parapet; disc flat when fully expanded, never completely retractile; mouth rounded, with two œsophageal grooves; tentacles of two kinds, centripetal and peripheral; centripetal tentacles short, conical, arranged in three cycles, the inner cycles consisting of about 48 in number; peripheral tentacles arranged in four or five cycles consist of about 192 tentacles; aboral aspect of each

tentacle smooth, oral aspect flattened with lateral swellings alternately large and small.

Colour.—Column, cream below, passing into gray above, lower portion streaked or spotted with red-lead colour; suckers and marginal crenulations white; disc, central area cream-colour, with dark brown lines; area of the inner cycles of tentacles dark brown, a white spot in front of each tentacle; the inner tentacles have a madder tinge with a green sheen on their oral aspect; marginal tentacles transparent brown aborally, cream colour orally, the swollen portion spotted in the middle.

Dimensions.—Height, about 100–130 mm.; diameter of corona, 250 mm.; largest tentacles, 30 mm. × 6 mm.

Habitat.—Fringing reef, Mer.

Phymanthus muscosus, n. sp.

Form.—Forty-eight rows of small tubercles on upper portion of column; crenulated parapet; flat, completely retractile disc; small round mouth; 96 tentacles, bearing alternately large and small dendritic appendages.

Colour.—Column, various shades of gray, darker above than below; disc green with dark or light spots; tentacles gray with green appendages.

Dimensions. — Height, 250–500 mm. Diameter of corona, 500–750 mm.

Habitat.—Surface of fringing reef, Mer.

This species is allied to the type species of the genus, *P. loligo* (Ehr.); but the lateral appendages to the marginal tentacles are more dendritic that in the latter species, and the rosette-like disc-tentacles are absent. It is also very close to *Thelaceros rhizophoræ,* Mitch.[1] This genus cannot stand, but we believe it is to be a distinct species. *Phymanthus simplex* is a well-marked species.

---

[1] P. C. Mitchell, "Thelaceros rhizophoræ, n.g. et sp., an Actinian from Celebes,'—Quart. Jour. Micr. Sci. xxx., (N.S.), 1890, p. 551.

THALASSIANTHINÆ.

THALASSIANTHIDÆ.

Actineria dendrophora, n. sp.

Form.—Column, soft, smooth; base slightly expanded; oral disc greatly expanded, and irregularly folded or puckered, with its edge produced into lobes some 300 or 400 in number; the aboral aspect of the lobes is closely crowded with globular, pedunculated tentacles, the oral or upper surface being covered with ramified tentacles, these latter extend along the disc, in radial series, to a greater or less extent, but none reach the mouth; alternating with the lobes are comparatively large dendritic tentacles, these are more aborally situated than the lobes; disc, smooth, inclined to be crateriform in the centre, non-contractile; mouth, rounded, on a cone with two gonidial grooves.

Colour.—Column, pinkish; disc, translucent pinkish brown, with a delicate green sheen; mouth pale; capitate tentacles, pink, with a cream-coloured speck on tip (they look just like pink pearls); dendritic tentacles of same colour as disc, but, owing to their round contour, the green sheen is more apparent, and this is especially so on the finer branches, which thus appear decidedly green.

Dimensions. — Column, height about 70 mm.; diameter, 45–50 mm.; diameter of disc, 125 mm.

Habitat.—Surface of reef, Mer.

This species is quite distinct from the only hitherto described species of the genus *A. villosa* (Quoy et Gaim.). The specific name is derived from the numerous small tree-like tentacles on the disc.

ACTININÆ.

ACTINIIDÆ.

Condylactis Gelam, n. sp.

Form.—Column, smooth, expanded at capitulum, which is furnished with suckers; disc feebly retractile; mouth, circular with two or three gonidial grooves; tentacles long, in six or seven cycles, from about 192 to 240 in number.

Colour.—Column, red-lead colour below, passing into creamy yellow above; underside of capitulum gray, with pale suckers; (*a*) disc and tentacles olive brown; mouth green; tentacles with a greenish contour, and tipped with magenta; (*b*) disc gray; tentacles dark gray, with a buff sheen.

Dimensions.—Height of column, 150 mm.; diameter, 44 mm.; diameter of corona, 177 mm.; length of tentacles, 45 mm.

Habitat.—On reefs at Mabuiag and Mer.

We name this species after a legendary hero of Torres Straits who migrated from Moa (a neighbouring island to Mabuiag) to Mer; the main hill of the latter island still bears his name.

Condylactis Ramsayi, n. sp.

Form.—Column, soft, about as high as broad, terminating above in a well-marked parapet, but without marginal spherules or suckers; disc, flat, considerably wider than the column, can be slowly but completely retracted; mouth, circular, with a variable number of gonidial grooves (2–7); tentacles, numerous, relatively short, about one-third of the diameter of the disc.

Colour.—Column, usually olive-brown or green, occasionally pale magenta, pink; disc, translucent olive-brown or cinder-colour; stomatodæum, whitish; tentacles, with a grayish-brown core and a green satin-like sheen, sometimes with a pale ring near the tip, or with the tip of a paler and brighter green.

Dimensions. — Height of column, about 38 mm.; diameter of disc, about 46 mm.

Habitat.—Reef, Waier (Murray Islands).

We would like to associate with this species the name of Dr. E. P. Ramsay, the energetic Curator of the Australian Museum, Sydney.

Condylactis aspera, n. sp.

Form.—Column, cylindrical, skin delicate; the whole of the body except the disc covered with small, very adhesive suckers, so that whenever touched this Actinian adheres to the foreign body like a *Synapta;* fragments of shells adhere to the body; large suckers occur on the upper portion of the column; mouth, elongated; two gonidial grooves; large tentacles in three or four cycles

$(6 + 6 + 12 + 24 = 48)$, the inner cycle much the largest; usually the tentacles are considerably swollen, but they can become quite slender and flaccid.

Colour.—Body, uniform pale, translucent yellow drab or buff, finely dusted with very minute brown spots; tentacles may be faintly banded and the disc slightly variegated with dark brown.

Dimensions.—Column, height 30 mm., or more; diameter, about 25 mm.; tentacles, 60–75 mm. long; extreme diameter of corona, 175–200 mm.

Habitat.—Surface of reef, Mer.

Although this species presents some features which are not characteristic of the other species of genus, we do not at present see any good reason for placing it elsewhere. The specific name refers to the adhesive character noted above.

Anemonia citrina, n. sp.

Form.—Column, soft, with parapet of well-defined spherules; disc feebly and imperfectly retractile; mouth round; tentacles of moderate length, about three cycles.

Colour.—Column, uniform pale lemon-yellow; disc and tentacles, burnt-umber brown.

Dimensions.—Height of column, 30–40 mm.; diameter of corona of largest specimen, 50 mm.; tentacles, 15 mm. in length.

Habitat.—Between tides, on seaward side of a mangrove swamp, Mabuiag.

This species is named from its lemon-like appearance.

Anemonia Kwoiam, n. sp.

Form.—Body, salver-shaped; upper portion of column when fully expanded extends beyond the insertion of the tentacles, and forms a distinct crenulated rim; disc, with a wavy margin; mouth, round, no gonidial grooves; no suckers on upper portion of column; tentacles in multiples of six.

Colour.—Column, buff; disc, burnt sienna brown, with white spots; tentacles, brown, speckled with white proximally.

Dimensions.—Corona, 155 mm., when fully expanded; tentacles, 22 mm. long.

Habitat.—Surface of reef, Mabuiag (Jervis Island).

We have identified this species with the name of Kwoiam, a renowned legendary hero of Mabuiag.

ACTINIOIDES,, n. g.

Actiniidæ (Antheadæ), with more or less prominent suckers on upper portion of column ; capitular margin, with conical acrorhagi, which are provided with a well-developed battery of nematocysts.

This new genus bears pretty much the same relation to the genus *Actinia* that *Condylactis* does to *Anemonia* (*Anthea*).

Actinioides Dixoniana, n. sp.

Form.—Column, covered with vertical rows of sucker-like verrucæ ; capitular margin provided with large conical acrorhagi ; tentacles in two cycles, *not* in multiples of six.

Colour.—Column, various shades of greenish grays and browns ; disc, dark greenish brown, with white markings ; tentacles, olive-brown, banded with greenish white or gray on oral aspect.

Dimensions.—Diameter of corona of largest specimen, 31 mm.

Habitat.—Fringing reef, Mabuiag.

We have carefully studied the anatomy of this form, and find that the irregularities in the arrangement of its mesenteries recall those which were studied by the brothers G. Y. and A. F. Dixon in *Bunodes thallia*, Gosse (*cf.* Proc. Roy. Dubl. Soc., N. S. VI., 1889, p. 310.) We give ourselves the pleasure of dedicating this species to these investigators.

Actinioides Sesere, n, sp.

Form.—Column, smooth, with about 24 vertical rows of verrucæ, which are small below, in the upper portion of the column these are larger, and somewhat irregular in their arrangement ; capitulum, provided with well-defined, conical acrorhagi ; disc, flat ; mouth, round, raised on small cone, with no gonidial grooves.

Colour.—Column, various shades of brown and gray ; verrucæ, bright green ; acrorhagi, light green, with dark spots ; tentacles, brownish white, sometimes with green sheen.

Dimensions.—Diameter of corona, 30 mm.

Habitat.—In crevices and holes in stones on the shore, Mabuiag, October, 1888.

This species is named after Sesere, the legendary hunter of the dugong, who lived on the neighbouring island of Badu (*cf.* "Legends from Torres Straits," Folk-lore, i., 1890, p. 23.

· **Viatrix cincta**, n. sp.

Form.—Tissues, delicate; column, short, cylindrical; capitulum produced into a very prominent rim, from which project at least six club-shaped enlargements, which may bear secondary tubercles on their aboral aspect; tentacles rather short, in three cycles (12 + 12 + 24 = 48).

Colour.—Ectoderm, colourless; but the endoderm everywhere shines through, with a brown colour; processes, with white ends; secondary tubercles, bright green.

Dimensions.—Height of column, 6 mm.

Habitat.—Surface of reef, Mabuiag, October, 1888.

This is probably an immature form; the specific name is derived from the girdle-like appearance of the capitular rim, beset, as it were, with bosses of emeralds. It appears to us to be allied to *Hoplophoria coralligens*, Wils.[1] Prof. Mac Murrich has, however, informed us that this species is *Viatrix globulifera* (Duch.), but we must confess to seeing but little resemblance between the figures given by Wilson and by Duchassaing and Michelotti.[2] If Dr. Wilson's species is a *Viatrix*, ours must, we think, be also placed in that genus.

BUNODIDAE.

Alicia rhadina, n. sp.

Form.—Columnar, when fully extended, conical when retracted; basal disc flat, adhering; scapus, delicate, with simple and compound tubercles mainly disposed in vertical series; capitulum, delicate, non-tuberculate; oral disc expanded, often crateriform,

---

[1] H. V. Wilson, "On a New Actinia, Hoplophoria coralligens." Studies Biol Lab. Johns Hopkins Univ. iv. Pl. xliii.

[2] "Mémoire sur les Coralliaires des Antilles." Mem. Reale Accad. Torino, (2) xix. 1860. Pl. vi., figs. 15, 16.

may be flat, or at times even conical; tentacles, 48 in number in two cycles, those of the inner cycle being the longer; mouth, oval, with twelve slight ridges, but no gonidial grooves; the whole animal is extremely delicate in texture.

Colour.—Body, translucent white, almost transparent; six vertical rows of brown, and six of white tubercles, all of which have a greenish gray apex, surrounded by a narrow ring of cream colour; the inner cycle of tentacles transparent and free from colour except a slight tinge of pale pink in some lights, outer cycle similar, but with a bright orange mark at their base, and a dark violet-brown oval spot.

Dimensions.—Column, when fully expanded, 30 mm. high and 17 mm. in diameter.

Habitat.—Albany Pass, Cape York, 10 fms.

The specific name is derived from the latinised form of ῥαδινὸς, delicate.

This species is undoubtedly allied to *Actinia pretiosa*, Dana, from Fiji. J. Y. Johnson (Proc. Zool. Soc. 1861, p. 298, and Ann. Mag. N. H., (3) IX. 1861, p. 177) described a new Actinian from Madeira, under the name of *Alicia mirabilis*, n. g. and sp. In 1868, Panceri named a Mediterranean Actinian *Cladactis Costæ;* and in the same year, but quite independently, Verrill erected a genus bearing the same name for his new species, *C. grandis*. Andres, in his monograph, "Le Attinie" (1884) p. 224, disregards Johnson's priority, although the original account was sufficiently clear, and adopts Panceri's genus, putting the three last-named species under it. He overlooks the relationship of Dana's species to the others, and suggests (p. 233) that it may be a new genus. Unless the name *Alicia* is pre-occupied, it must take priority of *Cladactis*, however appropriate the latter may be. The genus *Alicia* thus has for its type species *A. mirabilis*, Johns. and embraces *A. Costæ* (Panc.); *A. grandis* (Verr.); *A. pretiosa* (Dana), and *A. rhadina*, n. sp.

SAGARTIDÆ.

Phellia (?) sipunculoides, n. sp.

Form.—Body, columnar; pedal disc, flat, adherent; scapus, coriaceous, tesselated; capitulum, extensile, delicate; tentacles of

moderate length and thickness, somewhat longer than diameter of oral disc, inner cycle longer than the outer; oral disc, circular; mouth, oval, on a cone.

Colour.—Scapus, grayish drab, of the same colour as the coral which it inhabits; capitulum, translucent madder brown, with a white mark below each tentacle; tentacle and disc, olive brown, with a longitudinal white streak along their oral aspect, which is continued across the disc to the mouth.

Dimensions.—Length, when extended, 20 mm.; diameter of column, 12 mm.

Habitat.—In crevices of indurated dead coral rock, between tides, Cockburn Reef; N. Queensland.

The specific name is given to this form, on account of its resemblance when retracted to a contracted *Sipunculus nudus.*

Phellia (?) Devisi.

Form.—Body, short, stout, columnar; pedal disc flat, adherent; scapus, coriaceous, corrugated; capitulum, delicate; tentacles short, with a swollen base, length, about diameter of disc, inner cycles the longer; oral disc, circular; mouth oval, no gonidial grooves apparent.

Colour.—Scapus, buff; capitulum, translucent madder violet, with a ring of small white marks; tentacles, cream, with an interrupted dark line on oral aspect, base, dark brown, edged with bright deep green, the outer cycle without colour on base; oral disc, chestnut colour; lips, dark brown; stomatodæum cream.

Dimensions.—Height and diameter of column, about 7 mm.

Habitat.—Crevices of indurated dead coral rock, between tides, Cockburn Reef; N. Queensland.

We have named this species in honour of Mr. C. W. de Vis, the able Curator of the Queensland Museum, Brisbane.

Paraphellia Munti, n. sp.

Form.—Body, columnar, very contractile, when fully contracted like a scab; oral disc, but little exceeding the diameter of the column; tentacles in four cycles (6 + 6 + 12 + 24); mouth with two gonidial grooves.

Colour.—Column, mealy pink, with longitudinal gray bands;

tentacles, whitish; disc, mottled with orange, gray, white, and black.

Dimensions.—Height of column, about 10 mm.; average diameter, 8 mm.

Habitat.—Passage between reefs, Murray Islands; 15 fms.

[This species is named after my friend and host, the Rev. A. E. Hunt, of the London Missionary Society.—A. C. H.]

Paraphellia lineata, n. sp.

Form.—Oral and pedal disc, of about the same diameter; mouth, slit-like, on a cone; tentacles, very short in three or four cycles.

Colour.—Pale buff, with slightly darker rings on the tentacles; each radius on the disc is marked by series of fine dots, and a dark line up the oral cone.

Habitat.—Between Orman's Reef and Gaba ("Brothers' Island"), 6–7 fms., August 18, 1888.

The specific name refers both to the linear marking on the oral disc and to the serried appearance of the sphincter muscle as seen in section.

Thoe (?) Milmani, n. sp.

Form.—Body, soft; large pedal disc; oral disc not much exceeding diameter of column; tentacles, numerous, short; mouth, oval.

Colour.—Column of a smoky-yellow colour, sparsely speckled with dark brown; tentacles, pale creamy yellow, with a central broad, ash-coloured band.

Dimensions.—Diameter of corona, 30 mm.

Habitat.—Albany Pass, Cape York, 10 fms., August 29, 1888.

[Named after Mr. H. Milman, whose guest I was on board the Government steamer, and who was then acting as Government Resident in Torres Straits.—A. C. H.]

Adamsia miriam, n. sp.

Form.— Base, much expanded; body, columnar, smooth; oral disc, slightly expanded, completely retractile; mouth, linear, two gonidial grooves; numerous short tentacles in at least five cycles.

Colour.—Column, brown, the 24 cinclides yellowish white, base, pale, with six irregular brown blotches ; corona, mottled, with six radial patches of dark brown in which all the tentacles have the same colour, whereas in the lighter patches they are annulated.

Dimensions.—Diameter of basal disc, about 40 mm. ; height of column, 27 mm. ; average diameter, 18 mm.

Habitat.—On shell of *Dolium*, inhabited by a hermit-crab ; from surface of reef, Mer.

The specific name is the native name for anything appertaining to Mer.

There are a few more species in the collection which we have not yet named.

X.

ON *HEMITRYPA HIBERNICA*, M‘COY, By GRENVILLE A. J. COLE, F.G.S., Professor of Geology in the Royal College of Science for Ireland. PLATE VIII.

IN the Spring of 1892, Mr. R. Kirwan, B.A., brought me some specimens of Fenestellid polyzoa from the Carboniferous Limestone of Gardenfield, near Tuam, Co. Galway, which were covered over with what appeared to be an outer sheath (Pl. VIII., fig. 5). Very short inspection sufficed to convince one that these were referable to *Hemitrypa*, Phillips ; but, on examining the British literature relative to this genus, a certain chill was cast upon the investigation.

Phillips (1, p. 27) described his type, *Hemitrypa oculata*, as " a thin lamina of coral expanded in a cup-formed mass ; external surface wholly covered with numerous round pores or cells, radiating from a centre, and associated in double rows, which near the centre undergo frequent division, so as to form two such rows. Internal surface marked with radiating ridges, corresponding to the external interstices between the rows ; between these ridges are many oval depressions, which *penetrate only half through the substance of the coral, and nowhere reach the outer face.*

It grows to the size of two or three inches in diameter. The internal face was like that of some Fenestellæ, but the peculiarities of the external surface seem to demand generic separation. The specimens are extremely perfect.

Locality.—In South Devon : Barton.

The name is derived from ἥμισυς, half, and τρῦπα, a perforation. The figure given by Phillips (1, pl. xiii., fig. 38) is only a sketch, and the type-specimen has not yet come to hand in the collections of the Museum of Practical Geology, London ; but, by the kindness of Mr. E. T. Newton, I have there seen the fragment figured by Phillips as 38 *a*. There is no doubt that the relations of the two

layers in *Hemitrypa* were, in a broad way, correctly appreciated by the founder of the genus.

M'Coy (2, pp. 204–5), who probably had much better material in his hands, accepted the genus, describing it as " covered with an external (imperforate?) sheath." While referring some fragments to *H. oculata*, on account of the smallness and roundness of the openings in the external sheath, he established a new species, *Hemitrypa hibernica*, attributing the specific name to a manuscript note of Scouler. He states (2, p. 205) that this species has an external poriferous face, meaning, I presume, that the pores, or openings of the zoœcia, are on the face covered by the "sheath." He notes that there are about three pores to the length of a fenestrule, and adds :—" External sheath, nearly smooth, marked externally with faint, equidistant striæ, which coincide with the interstices of the internal net-work, and enclosing between them two alternating rows of large, rounded, or obscurely hexagonal depressions, coinciding with the openings of the internal net-work." This description is vague and only partial ; we should scarcely conclude from it that every pair of rows of " depressions " in the sheath overlies one of the rows of fenestrules (" openings ") in the internal net-work ; but this is probably what is meant, and is what specimens in the Griffith collection show. It is scarcely likely that M'Coy observed that the " depressions " corresponded to the " pores " or zoœcial openings, or he would have expressed the fact more clearly.

The only differences between *H. hibernica* and *H. oculata*, Phill., are in the large size of the openings or " depressions " in the sheath of the former, and the squarer form of its fenestrules ; and for these differences we must trust Phillips's figure for the present.

M'Coy was struck with the resemblance of the internal mesh of *H. hibernica* to *Fenestella membranacea*, Phill., and, in describing that species (2, p. 202), says, " I have recently seen a specimen exhibiting traces of the external sheath of *Hemitrypa*." Furthermore, he adds, with keen insight (2, p. 200), " *Hemitrypa* is possibly only the perfect state of *Fenestella*."

W. Lonsdale (3, p. 183), about the same date, described a third species, *H. sexangula ;* but he believed it to be really identical with

Fenestella fossula, and regarded the "investing crust" as a parasite. He admitted that the agreement between the openings of the two layers was "interesting" and "remarkable." This investigation was carried on with a hand-lens, and nothing was determined as to the nature of the outer layer.

Having, in fact, certain preconceived ideas as to the characters of the Fenestellidæ, various authors regarded a superposed feature with suspicion; but its rejection as an integral part of the organism was based upon very imperfect examination.

Sir Richard Griffith, who had before him the specimens examined by M'Coy, records *Hemitrypa* as a separate genus, the one well-recognized Irish species, *H. hibernica*, occurring in his lists in all the divisions of the Carboniferous Limestone (4, pp. 70, 76, and 81).

The late Mr. W. H. Baily (5, p. 107), describing drawings of *Fenestella membranacea* (*ibid.*, pl. 37, fig. 2 *b.*), wrote, "Portion of the upper or celluliferous surface, enlarged; this, when removed, exhibits impressions corresponding with the condition of the fossil named *Hemitrypa hibernica*, M'Coy." But the drawing shows, in its lower part, merely raised casts of the fenestrules. A little pit, a very common feature, occurs in the summit of these, perhaps by the contraction of the mud that first infilled the hollows of the organism; and this gives a casual resemblance to M'Coy's figure (2, pl. xxix., fig. 7) of the *outer* surface of *Hemitrypa*. But, as we shall see later, the raised ring-like bodies in M'Coy's drawing are based upon an optical illusion.

Mr. Baily continued to maintain the view that *Hemitrypa* was founded upon a mistake, despite the fact that M'Coy's specimens were close at hand in Dublin. Pencil-notes in his private copy of M'Coy's "Synopsis" show that Mr. Baily regarded the type-specimen as the result of an encrustation upon *Fenestella membranacea*.

This fact doubtless influenced Mr. G. W. Shrubsole (6, p. 281) during his review of the British Carboniferous Fenestellidæ. He asserts that the outer sheath of *Hemitrypa* is "without doubt a small coral common to the limestone, very similar to *Flustra palmata*, M'Coy, the empty calices of which cover over and conceal the *Fenestella* beneath. *Hemitrypa*, as we have seen, has *Fenestella*

membranacea, Phill., for the groundwork, and a microscopic coral or polyzoon for the superstructure."[1]

This statement carried weight by its simplicity and directness, and practically abolished *Hemitrypa* as far as the British Isles were concerned. I prefer to make no comment on it, as Mr. Ulrich has already dealt with the matter with the necessary precision (9, p. 354). Professor Nicholson, in 1879, in the second edition of his "Manual of Palæontology" (vol. i., p. 422), had given an account of *Hemitrypa;* but in the third edition (1889) the genus was excluded. Meanwhile, von Zittel (7, p. 601), basing his remarks upon Mr. Shrubsole's Paper, had given wide circulation to the idea that *Hemitrypa* was a superfluous genus, adding that it might be a *Fenestella* in a particular state of preservation. Doubtless owing to a deficiency of materials, this author did not remark, as M'Coy might have done, that if it was a *Fenestella*, the specimens of that genus, hitherto regarded as typical, must be held to be all in an imperfect state of preservation.

Hence, with Mr. Kirwan's interesting specimens before me, I felt that the simple process of cutting sections would set the question of the relations of the "sheath" at rest. Such sections, transparent or on smoothed surfaces of the rock, were exhibited at meetings of the Dublin Microscopical Club, where, from Dr. J. A. Scott and others, I gained valuable advice. They were amply sufficient to show that in Irish species of *Hemitrypa* the connexion between the two layers was fundamental and organic.

But on the American continent the researches of Prout (8, p. 444; pl. 17, fig. 4) had long ago led to the formation of correct opinions. Under the name of *Fenestella hemitrypa*, he gave the earliest accurate description of the genus *Hemitrypa*. His specimen was from limestone of Lower Carboniferous age, St. Louis County, Missouri, and was fortunately well preserved. Prout showed that the ribs of this Fenestellid bore a row of "projecting tubercles separating two lines of pores, . . . these tubercles unite at top and form slightly waved ridges in the direction of the longitudinal ribs, between which the lines of cells

---

[2] The same view was also emphasised by Mr. Shrubsole in dealing with British Silurian Fenestellidæ (Quart. Journ. Geol. Soc., vol. xxxvi. p. 242).

from opposite sides of the ribs meet,[1] and are cemented with the ridges into a common calcareous plate, supported by the lines of tubercles. When stripped of this crust, the keel appears to be a beautiful chain line of tubercles, with a line of pores on either side, as in other species of *Fenestella*." The fenestrules are " oblong, oval, frequently closed at bottom, or opening by a slight slit on the reverse surface." I find that Prout's measures give about 20 fenestrules to 1 centimetre, measured longitudinally, and 24 when measured transversely. The cells (zoœcia) are "large, about two to each fenestrule." The " cells " of the outer sheath are, however, said to be " invisible to the naked eye." This is probably due to the excellent condition of the specimen, the external opening in the outer sheath being smaller than the internal in the examples of *Hemitrypa* that I have examined, the structure being, in fact, a minute cup perforated at the bottom or outer end, and liable, therefore, to yield a larger external opening when worn down from the outside (see Pl. viii., fig. 3). I was led, indeed, for a short time to suppose that these openings in the sheath might have been, in Irish examples, completely closed over on the outer side.

Prout was the first, I believe, to show that the outer layer was supported away from the inner one by processes from the carinæ of the Fenestellid ribs; yet evidence could have been obtained by grinding down the end of any reasonable Irish specimen and examining the resulting section with a pocket-lens.

The reasons that prevented Prout from referring his species to *Hemitrypa* were founded, it seems to me, upon a misapprehension of Phillips's original description.

The importance of *Hemitrypa* was, however, never overlooked in the United States. Hall has described the species *prima*, *dubia*, *Nervia*, and *biserialis*,[2] all from Silurian (Niagara and Lower Hel-

---

[1] This is obscurely worded, but appears to mean that the " cells " of the outer sheath, borne by the tubercles of adjacent ribs, meet above the middle line between those ribs.

[2] *H. prima* was described in the Twenty-sixth Annual Report of the New York State Museum of Natural History, p. 98. *H. dubia* is figured in the Twenty-eighth Report (1875), pl. 11, figs. 17–21; but in the " State Museum Edition " of the Twenty-eighth Report (1879), p. 123, it is described as *Fenestella ambigua*. *Fenestella (Hemitrypa) Nervia* is described in the Thirty-second Report (1879), p. 173, and *F. (Hemitrypa) biserialis* in the same work, p. 174.

derberg) strata. The last-named is figured in the " Palæontology of the State of New York," vol. vi., pl. xxii., figs. 13–18; but the transverse section given is probably too small to convey a correct impression. Ulrich, however (9, pp. 559–565, and pls. xliv. and lvii.), has discussed six additional species, one of which is Devonian, while the remainder are from the Lower Carboniferous series. His sections (*ibid.*, pl. lvii.) are admirably illustrative. He reintroduces Prout's *Fenestella hemitrypa* under the name of *Hemitrypa proutana* ; and the resemblances are undoubtedly close. If the type-specimen really has such small openings in the sheath as figured by Prout, the wearing away of the surface, as already hinted, would give the more open mesh figured and described by Ulrich (9, pl. lvii., fig. 1). Ulrich describes the fenestrules in his specimen as quadrangular on the reverse, and long oval on the obverse. Prout believed his to be slit-like or even closed on the reverse (8, p. 445) ; but the two species may at present be regarded as identical. *H. proutana* acquires an interest in this country as being a decidedly near relative of the Irish *H. hibernica.*

The specimens collected by Mr. Kirwan made it necessary to seek the type-specimen of M'Coy's species, which was known to have formerly been in the collection of Sir R. Griffith, now in the Museum of Science and Art, Kildare-street, Dublin. Dr. V. Ball, F.R.S., has kindly allowed me to examine the collection, and specimens have been selected that exhibit well the characters figured by M'Coy. The one to which I attach especial weight resembles his figure (2, pl. xxix, fig. 7) sufficiently closely to have been the type, if we may suppose that some irregularities were omitted in the drawing and that the lower portion has been since removed. No other specimen agrees approximately with the figure. In any case, there is sufficient agreement among the more perfect Irish specimens to enable us to redefine *Hemitrypa hibernica.*

In so doing, I have greatly felt the need of a term for the " outer sheath," and one that could also be used adjectivally. I venture here to employ *tegmen* for this purpose. It may be worth remarking that Ulrich very properly speaks of the openings in the tegminal mesh as "interstices," while M'Coy and others have used the term " interstice " for the main columns, branches, or ribs, of Fenestellidæ. In the following description I follow M'Coy's original mode of definition as far as possible.

HEMITRYPA HIBERNICA, M'Coy.

Zoarium at times 13 cm. or more in height, irregularly conical or flabellate (Pl. VIII., fig. 5). *Branches* or *columns* fairly straight, generally 20 in 1 cm.; ribbed on reverse in young forms, slightly keeled on obverse, the keel being produced into pillars at intervals of about 0·5 mm. (Pl. VIII., figs. 2 and 3). These pillars may be 0·25 mm. long, and, by expansions of their outer ends, form, parallel to each column, a slightly waved bar, which becomes an integral part of the tegmen (Pl. VIII., fig. 1).

Fenestrules elliptical, larger on the reverse; length about 0·5 mm., width 0·25 to 0·3 mm. Typically 16 in 1 cm. measured along the columns. As few as 12 occur in one example.

Dissepiments thinner than the columns.

Zoœcia typically 40 in 1 cm. measured longitudinally (thus, as M'Coy says, about three to the length of a fenestrule).

Tegmen formed of " scalæ " (10, p. xxiii), distinctly continuous with the crests of the pillars that rise from the keels of the main columns, producing a delicate mesh with circular apertures, which sometimes appear by illusion hexagonal. These apertures are alternately arranged in double series, each series corresponding with the series of zoœcial pores beneath it. The bar formed by the crests of the pillars is so slightly wider than the scalæ, and than the midrib that results from their union, that the whole meshwork presents a very uniform texture (Pl. VIII., fig. 3). Its openings are wider in diameter on the inner face; from 32 to 46, typically 40, lie in 1 cm. measured longitudinally, and from 34 to 44 measured transversely. (The probable type-specimen shows variations from 32 to 36 tegminal apertures longitudinally, and gives 40 on transverse measurement. Another specimen varies from 34 to 40 in a transverse direction).

M'Coy's figure (2, pl. xxix, fig. 7, left-hand upper drawing) of an enlarged portion of the outer surface of the tegmen exactly represents what is seen in certain lights on the surface of the supposed type-specimen. But careful observation under a dissecting-microscope shows that this appearance varies with the direction in which the light falls. The dark mesh-structure can, in reality, be proved to be raised; it is the true tegmen. The white rings of

M'Coy's figure are on the floor of the infilled interstices of the tegmen, and are thus depressed; they are smooth and lustrous surfaces, of the same light-gray colour as the tegmen, and perhaps represent an adherent calcareous infilling of the aperture anterior in origin to the final choking of the whole structure.

After numerous measurements, the structure being entirely the same, I have utilized Mr. Kirwan's specimens from Co. Galway in supplying some of the detailed matter in the above description of *Hemitrypa hibernica*.   In such a Fenestellid there are three seemingly independent points of structure that may be employed in comparing one specimen with another.   These are (*a*) the number of columns or branches in 1 cm.; the number of rows of fenestrules will be the same as this, and the number of rows of tegminal apertures, measured transversely, will be double this figure; (*b*) the number of tegminal apertures in 1 cm., measured longitudinally; this, as we now know, agrees with the number of zoœcial apertures, which is often more difficult to measure directly; (*c*) the number of fenestrules in 1 cm. measured longitudinally.   To ascertain precisely the value of these quantities in specific determination, I tabulated six Irish specimens in the following three ways, adding Prout's *Fenestella hemitrypa* and Ulrich's *H. proutana* for comparison, since the general structure in all these seemed very closely similar.

The specimens thus used are :—

1. Probable type of *H. hibernica*, Griffith collection, from Lower Carboniferous Limestone, Little Id., Cork.   A larger specimen from the same locality agrees so precisely as not to require separate tabulation.

2. Specimen labelled *Hemitrypa hibernica*, from Upper Carboniferous Limestone, Knockninny, Enniskillen.   Griffith collection.

3. Specimen similarly labelled, from Calp, Ballintrillick, Bundoran.   Griffith collection.

4. Specimen collected by Mr. Kirwan, from Carboniferous Limestone, Gardenfield, Co. Galway.

4*a*. Ditto, in darker limestone.

4*b*. Ditto, small specimen, in darker limestone.

5. From Prout's description of his Carboniferous *F. hemitrypa*.

6. From Ulrich's description of typical *H. proutana*.

In the tables the values used are as follows :—

I. *Horizontal measure*, number of columns in 1 cm. *Vertical measure*, number of fenestrules in 1 cm. measured longitudinally.

II. *Horizontal measure*, number of tegminal openings in 1 cm. measured longitudinally. *Vertical measure*, as in I.

III. *Horizontal measure*, as in II. *Vertical measure*, number of columns in 1 cm.[1]
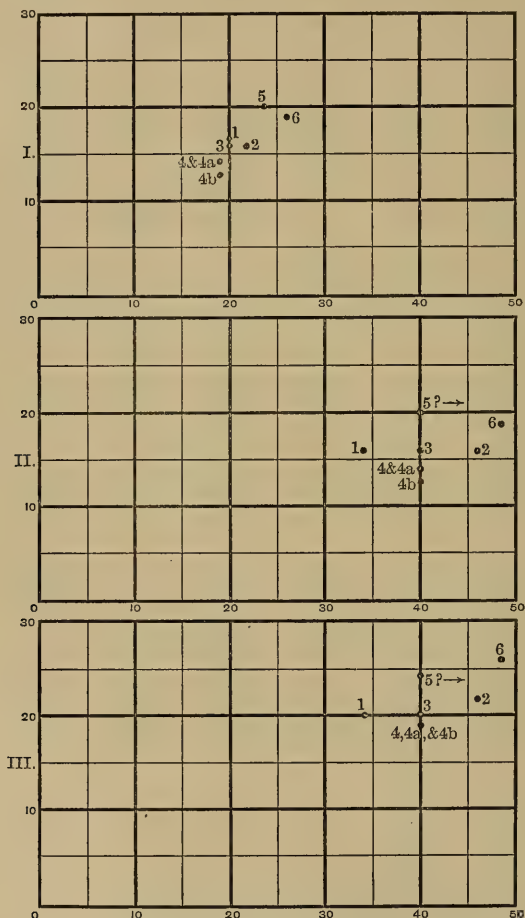
Tabulation of characteristics of specimens of *Hemitrypa hibernica* and *H. proutana.*

<hr>

[1] This method of tabulating individual characters, due to Prof. Call, was brought into prominence by Mr. G. K Gilbert ("Special Processes of Research," Amer. Journ. of Science, vol. xxxiii. p. 464)

Judged by these combinations of characters, the Galway speci-
mens are seen, by their positions in the tables, to be practically
identical, and also identical with 3, one of Griffith's and M'Coy's
specimens of *H. hibernica.* 1 and 2, which are important specimens,
diverge from this group only on account of variations in the number
of zoœcia (tegminal openings) per centimetre. The agreement in
other points is so close that I would regard the whole group 1 to
4b. as illustrating typically *H. hibernica*, admitting the range in
the number of the zoœcia.

But 5 and 6, representing the nearest American species, stand
away from the Irish group. Prout's statement that there are
about two zoœcia to each fenestrule may easily cover a larger
number, and, as indicated by the arrow on tables II. and III.,
may bring his account closer to that of Ulrich; such proximity is
seen in table I., which is based on another pair of characters. The
American species *H. proutana* may, I believe, be regarded as a
mere variety of the prior *H. hibernica;* but it is distinctly marked
by a more delicate structure throughout than is the case in the
Irish forms at present studied. The range of horizon and locality
in the latter is good evidence that the characters above stated fairly
represent the species *H. hibernica.*

The Galway specimens are here figured (Pl. VIII.); fig. 3 shows
a very happy dissection of the zoarium, produced by fracture of a
thin slice. The great secondary thickening on the reverse of the
columns has been pulled away, disclosing the original delicate
ribbing. The original more transparent zoœcial wall is also well
seen in fig. 1. The thickening takes place in waved layers as if
delicate spines were first shot out, between which the further
calcareous deposition went on. Similarly in sections of *Carinopora
Hindei*, kindly lent me by Dr. G. J. Hinde, the great keel is
seen to be built up around a delicate and more transparent central
lamina.

With regard to the nature of the animal that dwelt in the
zoœcia of *Hemitrypa*, and yet protruded itself far enough through
its narrowed vestibule to reach, and require a special aperture in,
the outer tegmen, one can only point out that its habits must have
frequently brought it into contact with the tegmen, and that its
tentacles probably extended beyond that meshwork. Indeed, the
tegminal openings in most *Hemitrypas* suggest that the mesh is

formed by the union of rings developed around the protruded ends of the polypides, rather than by any regular disposition of rod-like scalæ. But we have, thanks to the researches of Nicholson, Hall, and Ulrich, a beautiful series of Fenestellids from *Carinopora*, Nich. (11, p. 81), *Unitrypa*, Hall, and *Isotrypa*, Hall, to the well-established *Hemitrypa*, Phill.[1] We may conceive how the keels of *Carinopora* were useful for the protection of greatly extended polypides; how scalæ, slight and irregular, or finally more massive, as in *Unitrypa* and *Isotrypa*, would serve to support the anterior portion of these animals; and how, indeed, a permanent protrusion of the polypides may have occurred, the tentacles then arising at the well-arranged tegminal apertures, while a membraneous tube, perhaps, extended back from each of these to the true zoœcial opening. This is, however, clearly a difficult matter for speculation. The elementary conception of the Fenestellid zoœcium as a simple cyclostomatous calcareous tube has, at any rate, been long ago dispelled by the preparation of microscopic sections.

In addition to those friends whose kindness has been acknowledged in the paper, I would express my indebtedness to Professor H. A. Nicholson, F.R.S., Mr. G. H. Carpenter, B. SC., and especially to Dr. G. J. Hinde, Vice-President of the Geological Society of London.

---

[1] *Cryptopora,* Nich. (11, p. 77), from Ontario, cannot be regarded as completely known. It seems possibly a true *Hemitrypa.*

REFERENCES.

(1) Phillips, J.:

" Palæozoic Fossils of Cornwall, Devon, and West Somerset."—Ordnance Geological Survey, 1841.

(2) M'Coy, F.:

" A Synopsis of the characters of the Carboniferous Limestone Fossils of Ireland."—Dublin, 1844. (Reprinted, but not styled 2nd edition, in 1862.)

(3) Lonsdale, W.:

" Description of six species of corals, from the Palæozoic formation of Van Diemen's Land."—Appendix to part i. of C. Darwin's " Geological Observations on the Volcanic Islands, &c."—The 3rd edition is here quoted.

(4) Griffith, Sir R.:

" Localities of the Irish Carboniferous Fossils."—Journ. Geol. Soc. of Dublin, vol. ix. 1860–62.

(5) Baily, W. H.:

" Figures of Characteristic British Fossils."—Vol. i., Palæozoic. 1875.

(6) Shrubsole, G. W.:

" A Review of the British Carboniferous Fenestellidæ."—Quart. Journ. Geol. Soc., London, vol. xxxv., p. 275. 1879.

(7) Zittel, K. A.:

" Handbuch der Palæontologie."—Band i. 1880.

(8) Prout, H. A.:

" Third series of descriptions of Bryozoa from the Palæozoic rocks of the Western States and Territories."—Trans. Acad. Science of St. Louis, vol. i., p. 443. 1860.

(9) Ulrich, E. O.:

Geological Survey of Illinois.—Vol. viii., pp. 285–688. 1890.

(10) Hall, Jas.:

" Palæontology of the State of New York."—Vol. vi. 1887.

(11) Nicholson, H. A.:

" Descriptions of two new Genera and Species of Polyzoa from the Devonian Rocks."—Ann. and Mag. Nat. Hist., Ser. 4, vol. xiii., p. 77. 1874.

EXPLANATION OF PLATE VIII.

[All the figures are from specimens of *Hemitrypa hibernica*, from Garden-field, near Tuam, Co. Galway.]

FIGS.

1. Transverse section, viewed by transmitted light, showing four branches or columns, each with its pair of zoœcia. One of the zoœcia shows the aperture, directed towards the tegmen. In three cases a pillar-like process has been traversed, the outer expansion of which forms part of the tegmen. The primary ribbed reverse of the columns, with the more opaque secondary thickening, can be well seen. × 20.

2. Vertical section, viewed by transmitted light, showing the reverse on the left, and the zoœcia, with the pillars that support the tegmen, on the right. The tegmen itself is lost. × 30.

3. Dissection of a thin slice, viewed obliquely, showing the ribbed columns, from which the secondary deposit has been broken away; the inner face of the tegmen is seen on the right, and a transverse section of the whole structure occurs on the surface of the slice. Three dissepiments are also seen. × 8.

4. Section of limestone, viewed by reflected light, showing parts of several zoaria, crowded together, in various stages of growth. × 4.

5. External view of a zoarium, the tegminal apertures being barely visible to the naked eye. In the upper left-hand portion the tegmen has been broken away, and the fenestrules, with remnants of the columns, can be seen. Natural size.

XI.

ON THE BRIGHT COLOURS OF ALPINE FLOWERS.
By J. JOLY, M.A., Sc. D., F.R.S.

It is admitted by all observers that many species of flowering plants growing on the higher alps of mountainous regions display a more vivid and richer colour in their bloom than is displayed in the same species growing in the valleys. That this is actually the case, and not merely an effect produced upon the observer by the scant foliage rendering the bloom more conspicuous, has been shown by comparative microscopic examination of the petals of species growing on the heights and in the valleys. Such examination has revealed that in many cases pigment granules are more numerous in the individuals growing at the higher altitudes. The difference is specially marked in *Myosotis sylvatica*, *Campanula rotundifolia*, *Ranunculus sylvaticus*, *Galium cruciatum*, and others. It is less marked in the case of *Thymus serpyllum* and *Geranium sylvatica*; while in *Rosa alpina* and *Erigeron alpinus* no difference is observable.[1]

In the following cases a difference of intensity of colour is, according to Kerner (" Pflanzen Leben," II. 504), specially noticeable :—*Agrostema githago*, *Campanula pusilla*, *Dianthus inodorus (silvestris)*, *Gypsophila repens*, *Lotus corniculatus*, *Saponaria ocymoides*, *Satureja hortensis*, *Taraxacum officinale*, *Vicia cracca*, and *Vicia sepium*.

To my own observation this beautiful phenomenon has always appeared most obvious and impressive. It appears to have struck many unprofessional observers. Helmholtz offers the explanation that the vivid colours are the result of the brighter sunlight upon the heights. It has been said, too, that they are the direct chemical effects of a more highly ozonized atmosphere. The latter expla-

---

[1] G. Bonnier, quoted by De Varigny, " Experimental Evolutions," p. 55.

nation I am unable to refer to its author. The following pages contain a suggestion on the matter, which occurred to me while in the Linthal district of Switzerland last summer. I have some compunction in offering the suggestion of an unprofessional.

If the bloom of these higher alpine flowers is especially pleasing to my own æsthetic instincts, and markedly conspicuous to me as an observer, why not also especially attractive and conspicuous to the insect whose mission it is to wander from flower to flower over the pastures? The answer to this question involves the hypothesis I would advance as accounting for the bright colours of high-growing individuals. In short, I believe a satisfactory explanation is to be found in the conditions of insect life in the higher alps.

In the higher pastures the summer begins late and closes early, and even in the middle of summer the day closes in with extreme cold, and the cold of night is only dispelled when the sun is well up. Again, clouds cover the heights when all is clear below, and cold winds sweep over them when there is warmth and shelter in the valleys. These rigorous conditions the fertilizers have to contend with in their search for food, and that when the rival attractions of the valleys below are so many. I believe it is these rigorous conditions which are indirectly responsible for the bright colours of alpine flowers. For such conditions will bring about a comparative scarcity of insect activity on the heights; and a scarcity or uncertainty in the action of insect agency in effecting fertilization will intensify the competition to attract attention, and only the brightest blooms will be fertilized.[1]

This will be a natural selection of the brightest, or the

---

[1] Mr. Grant Allen, I have recently learned, advances in " Science in Arcady " the theory that there is a natural selective cause fostering the bright blooms of alpines. The selective cause is, however, by him referred to the greater abundance of butterfly relatively to bee fertilizers. The former, he says, display more æsthetic instinct than bees. In the valley the bees secure the fertilization of all. I may observe that upon the Fridolins Alp all the fertilizers I observed were bees. I have always found butterflies very scarce at altitudes of 7000 to 8000 feet. The alpine bees are very light in body, like our hive bee, and I do not think rarefaction of the atmosphere can operate to hinder its ascent to the heights, as Mr. Grant Allen suggests. The observations on the death-rate of bees and butterflies on the glacier, to be referred to presently, seem to negative such a hypotheses, and to show that a large preponderance of bees over butterflies make their way to the heights.

brightest will be the fittest, and this condition, with the fact of heredity, will encourage a race of vivid flowers. On the other hand, the more scant and uncertain root supply, and the severe atmospheric conditions, will not encourage the grosser struggle for existence which in the valleys is carried on so eagerly between leaves and branches, and so the struggle becomes refined into the more ethical one of colour and brightness between flower and flower. Hence the scanty foliage and vivid bloom would be at once the result of a necessary economy, and a resort to the best method of securing reproduction under the circumstances of insect fertilizing agency. Or, in other words, while the luxuriant growth is forbidden by the conditions, and thus methods of offence and defence based upon vigorous development, reduced in importance, it would appear that the struggle is greatly referred to rivalry for insect preference. It is probable that this is the more economical manner of carrying on the struggle.

As regards the conditions of insect life in the higher alps, it came to my notice in a very striking manner that vast numbers of such bees and butterflies as venture up perish in the cold of night time. It appears as if at the approach of dusk these are attracted by the gleam of the snow, and quitting the pastures, lose themselves upon the glaciers and firns, there to die in hundreds. Thus in an ascent of the Tödi from the Fridolins hütte I counted in the early dawn sixty-seven frozen bees, twenty-nine dead butterflies, and some half-dozen moths on the Biferten glacier and firn. These numbers, it is to be remembered, only included those lying to either side of our way over the snow, so that the number must have mounted up to thousands when integrated over the entire glacier and firn. Approaching the summit none were found. The bees resembled our hive bee in appearance, the butterflies resembled the small white variety common in our gardens, which has yellow and black upon its wings. One large moth, striped across the abdomen, and measuring nearly two inches in length of body, was found. Upon our return, long after the sun's rays had grown strong, I observed some of the butterflies showed signs of reanimation. We descended so quickly to avoid the inconvenience of the soft snow that I had time for no observations on the frozen bees. But dead bees are common objects upon the snows of the alps.

These remarks I noted down roughly while at Linthal this summer, but quite recently I read in "Natural Science" for December, 1892, vol. i., p. 730, the following note:—

" *Late Flowering Plants.*—While we write, the ivy is in flower, and bees, wasps, and flies are jostling each other and struggling to find standing-room on the sweet-smelling plant. How great must be the advantage obtained by this plant through its exceptional habit of flowering in the late autumn, and ripening its fruit in the spring. To anyone who has watched the struggle to approach the ivy-blossom at a time when nearly all other plants are bare, it is evident that as far as transport of pollen and cross-fertilization go, the plant could not flower at a more suitable time. The season is so late that most other plants are out of flower, but yet it is not too late for many insects to be brought out by each sunny day, and each insect, judging by its behaviour, must be exceptionally hungry.

" Not only has the ivy the world to itself during its flowering season, but it delays to ripen its seed till the spring, a time when most other plants have shed their seed, and most edible fruits have been picked by the birds. Thus birds wanting fruit in the spring can obtain little but ivy, and how they appreciate the ivy berry is evident by the purple stains everywhere visible within a short distance of the bush."

These remarks suggest that the ivy adopts the converse attitude towards its fertilizers to that forced upon the alpine flower. The ivy bloom is small and inconspicuous, but then it has the season to itself, and its unobservability is no disadvantage, *i. e.* if one plant was more conspicuous than its neighbours, it would not have any decided advantage where the fertilizer is so abundant and otherwise unprovided for. Its dark-green berries in spring, which I would describe as very inconspicuous, have a similar advantage in relation to the necessities of bird life.

The experiments of M. C. Flahault must be noticed. This naturalist grew seeds of coloured flowers which had ripened in Paris; part in Upsala, and part in Paris; and seed which had ripened in Upsala part at Paris, and part at Upsala. The flowers opening in the more northern city were in most cases the brighter.[1]

---

[1] Quoted by De Varigny, "Experimental Evolution," p. 56.

If this observation may be considered unquestionable, as appears to be the case, the question arises, Are we to regard this as a *direct* effect of the more rigorous climate upon the development of colouring matter on the blooms opening at Upsala? If we suppose an affirmative answer, the theory of direct effect by sun brightness must I think be abandoned. But I venture to think that the explanation of the Upsala experiment is not to be found in *direct* climatic influence upon the colour, but in causes which lie deeper, and involve some factors deducible from biological theory.

The organism, from the great facts of heredity of qualities and survival of the fittest, is necessarily a system which gathers experience with successive generations, and the principal lesson ever being impressed upon it by external events is economy. Its success depends upon the use it makes of its opportunities for the reception of energy and the economy attained in disposing of what is gained.

With regard to using the passing opportunity, the entire seasonal development of life is a manifestation of this attitude, and the fleetness, agility, &c., of higher organisms are developments in this direction. The higher vegetable organism is not locomotory, save in the transferences of pollen and seed, for its food comes to it, and the necessary relative motion between food and organism is preserved in the quick motion of radiated energy from the sun and the slower motion of the winds on the surface of the earth. But, even so, the vegetable organism must stand ever ready and waiting for its supplies. Its molecular parts must (spider-like) be ready to spring upon the prey offered to it. Hence, the plant stands ready, and every cloud with moving shadow crossing the fields handicaps the one organism to the benefit of the unshaded plant in the adjoining field. The open bloom is a manifestation of the generally *expectant attitude* of the plant, but in relation to reproduction.

As regards economy, any principle of maximum economy, where many functions have to be fulfilled, will, we may very safely predict, involve as far as possible mutual helpfulness in the processes going on. Thus the process of the development towards meeting any particular external conditions, A, suppose, will, if possible, tend to forward the development towards meeting conditions B; so that, in short, where circumstances of

morphology and physiology are favourable, the ideally economical system will be attained when in place of two separate processes, a, β, the one process γ, cheaper than $a + \beta$, suffices to advance development simultaneously in both the directions A and B. The economy is as obvious as that involved in "killing two birds with the one stone," and although expressed here rather crudely, it is to be expected with certainty (I venture to think) that to foster such economy will be the tendency of evolution in all organic systems subjected to restraints as those we are acquainted with invariably are.

Such economy might be simply illustrated by considering the case of a reservoir of water elevated above two hydraulic motors, so that the elevated mass of water possessed gravitational potential [the daily gains or the stored-up reserve material of the organism]. How best may the water be conveyed to the two motors [the organic reactions towards conditions A and B] so that as little head as possible is lost in transit? If the motors are near together it is most economical to use the one conduit, which will distribute the requisite supply of water to both. If the motors are located far asunder it will be most economical to lay two pipes. [There is greatest economy in meeting a plurality of functions by the same train of physiological processes where this is consistent with discharging other functions necessitated by external or internal conditions.]

But an important and obvious consequence arises in the supply of the two motors from the one conduit. We cannot work one motor without working the other. If we open a valve in the conduit both motors start into motion and begin consuming the energy stored in the tank. And although they may both under one set of conditions be doing useful and necessary work for us, in some other set of conditions it may be quite needless for both to be driven.

This last fact is an illustration of a consideration which must enter into the phenomenon which an eminent biologist speaks of as physiological or unconscious "memory,"[1] and illustrates that in the organism its development from the ovum is but the starting of a train of interdependent events of a complexity depending upon the experience of the past.

---

[1] Professor Hering, quoted by Professor Ray Lankaster, "The Advancement of Science," p. 283.

In short, we may suppose the entire development of the plant, towards meeting certain groups of external conditions, physiologically knit together according as Nature tends to associate certain groups of conditions. Thus, in the case in point, climatic rigour and scarcity of fertilizing agency will ever be associated; and in the long experience of the past the most economical physiological attitude towards both is, we may suppose, adopted. So that the presence of one condition excites the apparent unconscious memory of the other. In reality the process of meeting the one condition involves the process and development for meeting the other.

And this consideration may be extended very generally to such organisms as can survive under the same associated natural conditions, for the history of evolution is so long, and the power of locomotion so essential to the organism at some period in its life history, that we cannot philosophically assume a local history for members of a species even if widely severed geographically at the present day. At some period in the past, then, it is very possible that the species to-day thriving at Paris, acquired the experience called out at Upsala. The perfection of physiological memory inspires no limit to the date at which this may have occurred—possibly the result of a succession of severe seasons at Paris; possibly the result of migrations—and the seed of many flowering plants possess means of migration only inferior to that possessed by the flying and swimming animals. But, again, possibly the experience was acquired far back in the evolutionary history of the flower.[1]

But a further consideration arises. Not only at each moment in the life of the individual must maximum income and most judicious expenditure be considered, but in its whole life history, and even over the history of its race, the efficiency must tend to be a maximum. This principle is even carried so far that when necessary it leads to the death of the individual, as in the case of

---

[1] The blooms of self-fertilising, and especially of cleistogamic plants (e.g. *Viola*), are examples of unconscious memory, or unconscious "association of ideas" leading to the development of organs now functionless. The *Pontederia crassipes* of the Amazon, which develops its floating bladders when grown in water, but aborts them rapidly when grown on land, and seems to retain this power of adaptation to the environment for an indefinite period of time, must act in each case upon an unconscious memory based upon past experience. Many other cases might be cited.

those organisms which, having accomplished the reproductive act, almost immediately expire. This view of nature is very repellent to us who reflect and are self-conscious. But it is, nevertheless, evident that we are but parts of an economical system which ruthlessly sacrifices the individual on general grounds of economy. Thus, if, in the life history of any individual organism, the (imaginary) curve which defines the mean rate of reception of energy at different periods of life be opposed by a second curve
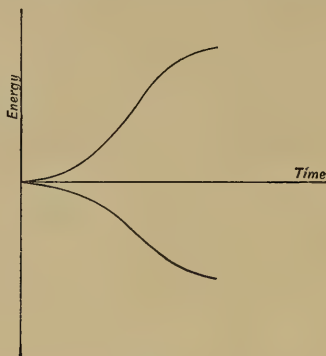
drawn below the axis along which time is measured, representing the mean rate of expenditure of energy (see fig.), this curve must be of such a nature from its origin to its completion in death, when there is no further expenditure of energy except in the post-vital disintegration of the body, that the condition is realized of the most economical rate of expenditure at each period of life.[1] The rate of expenditure of energy at any period of life is, of course, in such a curve defined by the slope of the curve towards the axis of time at the period in question; but this particular slope must be led to by a previous part of the curve, and involves its past and future course to a very great extent. There will, therefore be impressed upon the organism by the factors of evolution a unified course of economical expenditure completed only by its death, and which will give to the developmental progress of the individual its prophetic character.

In this way we philosophically look to the unified career of each organic unit, from its commencement in the ovum to the

---

[1] See " The abundance of Life," these Proceedings, *ante,* Vol. vii., p. 78.

day when it is done with vitality, for the explanation of that preparation for momentous organic events which is in progress throughout the entire course of development, and to the economy involved in the physiological welding of processes for the phenomenon of physiological memory, wherein we see reflected, as it were, in the development of the organism, the association of inorganic restraints occurring in nature which at some previous period impressed itself upon the plastic organism. We may picture, somewhat crudely, the seedling at Upsala swayed by organic memory and the inherited tendency to an economical preparation for future events gradually developing towards the æsthetic climax of its career. In some such manner only does it appear possible to account for the prophetic development of organisms, not alone to be observed in the alpine flowers, but throughout nature.

And thus, finally, to the effects of natural selection and to actions defined by general principles involved in biology, I would venture to refer for explanation of the manner in which flowers on the Alps develop towards their unusual beauty.

XII.

SUGGESTION AS TO A POSSIBLE SOURCE OF THE ENERGY REQUIRED FOR THE LIFE OF BACILLI, AND AS TO THE CAUSE OF THEIR SMALL SIZE. By G. JOHNSTONE STONEY, M.A., D.Sc., F.R.S., Vice-President, Royal Dublin Society.

SOME bacilli, *e.g.* some of the nitrifying bacilli of the soil, are said to be sustained by purely mineral food. If this be the case they must be supplied with a considerable amount of energy to enable them to evolve protoplasm and the other organic compounds of which they consist, from these materials. Now many bacilli are so situated that this energy is certainly not obtained from sunshine, and it is suggested that it may be derived from the gases or liquids about them.

The average speed with which the molecules of air dart about is known to be nearly 500 metres per second—the velocity of a rifle bullet; and the velocity of some of the molecules must be many times this, probably five, six, or seven times as swift. We do not know so much about the velocities of the molecules in liquids as of those in gases, but the phenomenon of evaporation and some others indicate that they are at least occasionally comparable with those of a gas. Accordingly, whether the microbe derive a part of its oxygen or other nourishment from the gases, or from the liquids about it, it is conceivable that **only the swifter moving molecules** can penetrate the microbe sufficiently far, or from some other cause are either alone or predominantly fitted to be assimilated by it.

Now if this be what is actually taking place, the adjoining air or liquid must become cooler through the withdrawal from it of its swiftest molecules ; and in compensation, an amount of energy exactly equivalent to this loss of heat is imparted to the microbes and available for the formation within them of organic compounds.

It is further evident that if this be the source of energy upon which bacilli and cocci have to draw, the minutenes of their narrowest dimension will be of advantage—probably essential—to them. Presumably it would only be limited by such other necessary conditions as may forbid the diminution of size being carried beyond a certain point. The diameter of a bacillus is frequently as small as half or a third of a micron, which brings it tolerably well into the neighbourhood of some molecular magnitudes.

The transference of energy here suggested may be what occurs notwithstanding that it does not comply with the Second Law of Thermodynamics, which states that heat will not pass from a cooler to a warmer body, unless some adequate compensating event occurs, or has occurred, in connexion with the transference. This law represents what happens when vast numbers of molecular events (which are the real events of nature) admit of being treated statistically, and furnish an *average* result. It, therefore, has its limits: and the communication of energy from air to minute organisms, which is described above, is an example of a process which is exempt from its operation; since this transference is supposed to be brought about by a *discriminating* treatment of the molecules that impinge upon the bacillus of precisely the same kind as that which Maxwell pictured as made by his well-known demons. It, therefore, belongs to the recognized exception[1] to the Second Law of Thermodynamics, viz. that which

---

[1] [*Addition received February* 20, 1893.]—If the reader has any doubt as to whether the process described in the text is one of those that contradict the Second Law of Thermodynamics, he may satisfy himself on this head by the following considerations:—

Imagine a perfect heat-engine within an adiabatic envelope, with some bacilli and an abundance of their mineral food, all being at one temperature. If events take place as supposed in the text, the bacilli receive sufficient energy from the surrounding medium to enable them to assimilate their mineral food, and thereby to grow and multiply. Meanwhile the medium becomes cooler. We may then suppose that the new bacilli which have come into existence, and all the excreta, are used as fuel in the heat-engine, and that its refrigerator is as near as we please to being at the temperature to which the medium has been reduced. The combustion of the fuel may take the form of resolving the bacilli and excreta back into the mineral substances from which they had been evolved, except that these are now at the temperature of the combustion. Let us next reduce this temperature in the heat-engine to the temperature of the refrigerator. During this process a portion of the heat may be converted into mechanical energy, and at the end of the process everything within the enclosure is in the same state as at the beginning, with the sole exceptions that some of the bodies within the

occurs in the few cases in which we can have under observation the special consequences of *selected* molecular events, instead of, as on all ordinary occasions, being only able to measure an *average* outcome from *all* the molecular events in the portion of matter we are examining.

If some bacilli—those which live on mineral food—obtain their whole stock of energy in the way here indicated, it may be presumed that all bacilli get at least a part of what they require in the same way.

---

enclosure are now at a lower temperature than at the beginning, and that the heat which they have lost has been converted into mechanical energy.

It thus appears that the contents of the adiabatic envelope may be regarded as a heat-engine, all the parts of which start at a certain temperature, and which yields mechanical energy, while the only other change is that some of its parts are cooled to a lower temperature. This contradicts the Second Law of Thermodynamics as formulated by Lord Kelvin, if we leave the word "inanimate" out of his enunciation. His statement of the axiom is:—"It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of surrounding objects." It is legitimate here to omit the word "inanimate," as its insertion merely means that cases of exception to the law may be met with in the organic world, and if this be stated it will need to be added that cases of exception may also be found among inorganic processes; the correct statement being that the law does not apply to *individual* molecular events, and that therefore it need not be obeyed in the cases, whether organic or inorganic, in which any observable effect is the outcome of one-sided molecular events.

It should be borne in mind that the heat of a given portion of matter is the energy of motions of and within its molecules; not necessarily of all such motions, but of those among them which are capable of restoring energy to the parts of the molecule carrying electra (see Stoney on Double Lines in Spectra, "Scientific Transactions of the Royal Dublin Society," Vol. iv., Part xi.) whenever the motion of the electron has transferred energy from the molecule to the æther. As fulfilling this criterion we are probably to include all irrotational motions within the molecules, and we must also include relative motions of the molecules—all of them indeed if time enough be allowed for turmoil within a fluid to subside. It does *not* include any motion which the molecules have in common, as in wind, or in the rotation of a wheel.

When these circumstances are taken into account, it is obvious that the energy of the heat motions of an individual molecule undergoes rapid fluctuations, while there may be a definite *average* of the energy of these motions, whether estimated by what happens in an individual molecule over a sufficiently long period of time, or when estimated by what occurs simultaneously in all the molecules of a body. In other words, the motions of an individual molecule do not from instant to instant conform to the Second Law of Thermodynamics, although the law may apply both to the average of the motions of a single molecule taken over a long period of time, and to the average of the simultaneous motions of vast multitudes of associated molecules. As regards *molecular* motions (the motions within a solid, or motions within a fluid that do not produce currents in the fluid), the millionth of one second is a long period.

XIII.

ON THE LAW OF GLADSTONE AND DALE AS AN OPTICAL PROBE. By PROFESSOR W. J. SOLLAS, D. Sc., LL.D., F.R.S.

THE law of Gladstone and Dale asserts the constancy of the ratio of the refractive index to the density for all substances, independent of the physical state in which they exist. It is expressed by the equation $\dfrac{n-1}{d} = \kappa$, where n signifies the refractive index, d the density, and κ a constant known as the specific refractive energy. If the specific refractive energy of any substance be multiplied by the molecular weight (m), a number is obtained known as the refractive equivalent, which may be indicated by the Greek letter Λ.

If, as verified by experiment, the elements retain their refractive equivalents unchanged in the state of chemical combination the refractive equivalent of a compound will be the sum of the refractive equivalents of its elements. Thus in the case of sodium oxide we have $2\text{Na}_\Lambda + \text{O}_\Lambda = \text{Na}_2\text{O}_\Lambda$. Hence, given the refractive equivalents of the elements, we can find the specific refractive energy (κ) of the compound : for, calling the molecular weight m, we have : $m\kappa = \text{Na}_2\text{O}_\Lambda$, and consequently,

$$\kappa = \frac{\text{Na}_2\text{O}_\Lambda}{m} = \frac{2\text{Na}_\Lambda + \text{O}_\Lambda}{m}.$$

Again, since $\dfrac{n-1}{d} = \kappa$, given κ and d, we can find the refractive index, or given κ and the refractive index, we can find the density.

This is true for both isotropic and anisotropic crystals, the refractive index in the latter being taken as the mean of the different indices corresponding to the three chief axes of elasticity. But since the law of Gladstone and Dale holds good when n is taken as the mean of the indices in a doubly refracting crystal, we may naturally inquire what signification it can have for the maximum, mean, and minimum indices.

If in the case of a uniaxial crystal we put $\dfrac{n_\omega - 1}{d_1} = \kappa$, $\dfrac{n_\epsilon - 1}{d_2} = \kappa_2$, n_ω and n_ϵ standing for the maximum and minimum indices, respectively, three suppositions are possible. κ_1 and κ_2 may have identical values, and then d_1 and d_2 must be different, *i.e.* the density of the crystal must be different in different directions; those, namely, of the optic axis and equatorial plane, or d_1 and d_2, may be identical, in which case κ_1 and κ_2 must vary directly as the refractive powers, or the specific refractive energy must be different in different directions; this supposition, like the last, leading to the conclusion that the constituent chemical atoms are differently arranged in different directions. Finally, we may suppose that both κ and d vary, and then both the previous conclusions will be true; the density and chemical composition will both differ, according to direction in the crystal.

But if the constancy of the specific refractive energy or of the refractive equivalents of the elements be maintained in an anisotropic crystal, as we have seen it is, then the possibility suggests itself of using this constancy as a means of exploring the molecular structure of the crystal; in other words, of using Gladstone and Dale's law as an optical probe.

As an example, we may select the two similarly constituted salts, potassium and sodium nitrates, the latter crystallizing in rhombohedra of the hexagonal system; the former likewise in rhombohedra, but also in forms belonging to the rhombic system: the refractive indices of potassium nitrate, however, are only known for the rhombic forms. The optic sign is in both cases negative, and the refractive indices are as follows :—

Potassium nitrate,	n_g	1·5052	n_m 1·5046	n_p	1·333 ;
Sodium nitrate, .	n_ω	1·586		n_ϵ	1·336.

It will be observed that the maximum and median indices of potassium nitrate, which are nearly equal, differ considerably from the maximum index of sodium nitrate ; on the other hand, the minimum indices of the two salts are of nearly identical value. If, as we suppose, the refractive indices stand in close connexion with the chemical constituents of the salt, we shall naturally conclude that the lower indices, which are almost the same in both compounds, are connected with the radicle, which is the same in both, *i. e.* the nitric oxide ; while the indices, which are markedly different, will stand in direct relation to the basic radicles, sodium and potassium oxyles.

In other words, between these two salts there exist two similarities and two differences. The two similarities are correspondences between the like chemical composition and the like refractive indices ; the two differences are also correspondences, but in their case between the unlike chemical constituents and the unlike refractive indices.

To these two may indeed be added a third, since an equally striking correspondence is to be noted between the similar dispersion for the minimum index in both salts (the value of $n_{p_{\mathrm{H}}} - n_{p_{\mathrm{B}}}$ being 0·0108 for KNO_3, and 0·009 for $NaNO_3$) ; and again, between the very different dispersion for the maximum index in both, the value of $n_{g_{\mathrm{H}}} - n_{g_{\mathrm{B}}}$ for KNO_3 being 0·041, and for $NaNO_3$, 0·047.

Let us now consider what is the most probable arrangement of atoms in the sodium nitrate molecule. Evidently the pentad nitrogen is the centre of the system, and one face looks towards sodoxyl and the other towards oxygen, thus $\begin{smallmatrix} -O \\ -O \end{smallmatrix}\!\!\diagdown\!\!\diagup N\!-\!O\!-\!Na$. But, again, the molecule must also conform to the symmetry of the rhombohedral system, and for this at least three sodium nitrate molecules must be conjoined, while to produce a rhombohedron six will be required. The following arrangement then results :— In the upper half of the molecule three atoms of nitrogen are linked together by three atoms of oxygen alternating with them, and along three radii, corresponding to the three upper edges of the rhombohedron, lie three molecules of sodoxyl, linked each by its oxygen atom to an atom of nitrogen which lies on the same radius. In the lower half of the molecule the same arrangement

is repeated, but the triradiate group is turned round through 60°, so that the –N–O–Na rays below lie midway between those above, and thus correspond to the three lower edges of the rhombohedron. Finally, the upper and lower moieties are united by six atoms of oxygen, which are linked to the nitrogen atoms, two of oxygen to each atom of nitrogen. Thus, each crystal molecule consists of six chemical molecules, each of the composition NO_3Na. It may be regarded as distributed in two differently directed groups, one consisting of oxygen (and so much of the nitrogen as belongs to it), six atoms of which are vertically linked, *i.e.* parallel to the optic axis, to a nitrogen atom ; and the other of six rays of –O–N–O–Na, the chemical bonds of which lie more or less parallel to the equatorial plane. It is essential to observe, that of the nitrogen atoms, only three out of five bonds of each are horizontally linked, and consequently we are led to assign only three-fifths of the molecular weight of this element to the equatorial members of the molecule, leaving the remaining two-fifths to the oxygen, which is linked vertically.

Let us now suppose a ray of light to enter our molecule along the optic axis, its wave front will lie in the equatorial plane or that in which the Na–O–N–O– members are supposed to act, and since in the direction of the optic axis there is only ordinary refraction we may connect these members with the ordinary refractive index. If, on the other hand, the path of the ray be parallel to the equatorial plane it will be resolved into an ordinary ray, the transversal of which being in the equatorial plane will be related to the equatorial members of the molecule, and an extraordinary ray, the transversal of which, being vertical, will be related to the vertically linked components. In this direction, in an optically negative crystal, such as sodium nitrate, the refractive index of the extraordinary ray has its minimum value, and it is this value which stands in direct relation to the refractive energy or refractive equivalents of the vertically linked atoms.

We are now in a position to apply our optical probe. If the structure of the crystal be that which we have suggested, the lower refractive index should be that due to the refractive energy of the vertical components of the molecule, and the higher, that due to the refractive energy of the equatorial component.

Then for Na–O–N$_{\frac{3}{2}}$–O– we have :—

$$\underset{23\ +\ 8\cdot4\quad +\ 32}{\overset{\overset{\text{Na}\qquad\text{N}_{\frac{3}{2}}\qquad\text{O}_2}{4\cdot89\ +\ 3\cdot198\ +\ 5\cdot56}}{}} = 0\cdot215 = \kappa_1$$

and

$$\frac{n_\omega - 1}{\kappa_1} = \frac{0\cdot5796}{\cdot215} = 2\cdot693 = d_1 ;$$

$$d_1 = 2\cdot693.$$

Again, for N$_{\frac{3}{2}}$–O– we have :—

$$\frac{\overset{\text{N}_{\frac{3}{2}}\qquad\text{O}}{2\cdot132\ +\ 2\cdot78}}{5\cdot6\ +\ 16} = 0\cdot2274 = \kappa_2$$

and

$$\frac{n_\epsilon - 1}{\kappa_2} = \frac{0\cdot3353}{\cdot2274} = 1\cdot474 = d_2 ;$$

$$d_2 = 1\cdot474.$$

The study of atomic volumes has rendered it highly probable that the sum of the atomic volumes of the constituents of a compound is equal to the total volume of the compound, and if this be so the sum of the partial volumes (*i. e.* of the groups Na–O–N$_{\frac{3}{2}}$–O– and N$_{\frac{3}{2}}$–O) should be equal to the volume of the whole salt NO$_3$Na.

Thus we have :—

$$\text{N}_{\frac{3}{2}}\text{O}_2\text{Na},\ \frac{m_1}{d_1} = \frac{63\cdot4}{2\cdot693} = v_1 = 23\cdot54,$$

$$\text{N}_{\frac{3}{2}}\text{O},\qquad \frac{m_2}{d_2} = \frac{21\cdot6}{1\cdot474} = v_2 = 14\cdot65,$$

and $23\cdot54 + 14\cdot65 = 38\cdot19$, while the volume found by dividing the molecular weight (85) of the whole salt by the density (2·246) is 37·85, a sufficiently close approximation.

The question will now arise whether or not some other distribution of the atoms in the molecule would not have afforded as equally an exact agreement. In order to decide this I have treated the molecule in a variety of ways, some probable, some the reverse, but in no case does such a close correspondence between the sum of the partial volumes and that of the whole salt result.

If true for sodium nitrate our treatment should also hold in

the case of potassium nitrate. In this case we must make use of the rhombic form, since the refractive indices have not been determined for the rhombohedral modification: the maximum and median indices which correspond to the ordinary index of sodium nitrate are so nearly equal that we may expect to get sufficiently approximate results by taking their mean as the index for the group $K–O–N_{\frac{2}{3}}–O–$. The calculations for this and succeeding salts are given in full in the extended Memoir; in this abstract it will be sufficient to state results. Thus for $K–O–N_{\frac{2}{3}}–O–$, $v_1 = 33·76$; and for $N_{\frac{2}{3}}–O–$, $v_2 = 14·73$, but $33·76 + 14·73 = 48·49$, and the total molecular volume of the salt is $48·8$. There is thus as complete a correspondence between the sum of the partial volumes and the volume of the compound as we found in the case of sodium nitrate.

Another pair of isomorphous compounds, with not very dissimilar extraordinary indices, is met with in the case of dihydric potassium arseniate and dihydric ammonium arseniate. Here we have :—

$$AsO_4KH_2; \quad n_\omega = 1·5674, \quad n_\epsilon = 1·5179.$$
$$AsO_4AmH_3; \quad n_\omega = 1·5774, \quad n_\epsilon = 1·5117.$$

The vertically acting groups will be $–O–As_{\frac{2}{3}}–O–K$, and $–O–As_{\frac{2}{3}}–O–NH_4$, the horizontally acting $H–O–As_{\frac{2}{3}}–O–H$ in both cases.

Calculating out in the same way as for sodium nitrate we obtain the following :—

$$As_{\frac{2}{3}}O_2K; \quad d_1 = 3·056, \quad v_1 = 37·96.$$
$$As_{\frac{2}{3}}O_2H_2; \quad d_2 = 2·482, \quad v_2 = 25·80.$$

The volume of the salt is $63·56$, the sum of the volumes of its components $37·96 + 25·80 = 63·76$.

$$As_{\frac{2}{3}}O_2NH_4; \quad d_1 = 1·933, \quad v_1 = 49·15.$$
$$As_{\frac{2}{3}}O_2H_2; \quad d_2 = 2·451, \quad v_2 = 26·11.$$

The volume of the whole salt is $75·15$, and the sum of the volumes of the component groups $49·15 + 26·11 = 75·26$.

A mineral isomorphous with sodium nitrate is calcite, and if our hypothesis be true this should possess a similar molecular structure, capable of affecting rays of light in the same way. A molecule of calcite should then consist of six atoms of carbon—three below at the corners of an equilateral triangle, and three above at

the corners of a similar triangle, but turned round 60° with respect to that below; six atoms of oxygen will link these carbon atoms vertically, and to each will be attached a molecule of calcoxyle, the atom of calcium in each calcoxyle molecule lying at the corner of the primitive rhombohedron. Thus a group $C_{\frac{3}{2}}O$ will determine the extraordinary index, and another $C_{\frac{3}{2}}O_2Ca$, the ordinary index. Again our construction gives partial volumes which equal in their sum the volume of the whole salt : thus the volume of $C_{\frac{3}{2}}O_2Ca$ is 26·12 ; of $C_{\frac{3}{2}}O$ it is 10·8 ; their sum is 36·92 ; and the volume of calcite is 36·9.

This result is consistent with what is known of the values of the atomic volumes of these constituents from independent evidence, as will be shown in the detailed Memoir.

Magnesite, isomorphous with calcite, gives equally satisfactory results. The volume of $C_{\frac{3}{2}}O_2Mg$ is 18·16 and of $C_{\frac{3}{2}}O, 10$; their sum is 28·16, and the volume of magnesite is 28.

Dolomite falls equally readily into line. The volume of $CaMgO_4C$ is 45, and of CO_2, 20·4, the sum is 65·4, and the volume of dolomite is 65·01. Arragonite and cerussite differ slightly in constitution, but they equally yield to our interpretation.

Calcium tungstate and lead molybdenate appear to be similarly constituted; at all events, in each, one may suppose that the arrangement which determines the refractive indices is similar in both; thus in calcium tungstate the horizontally acting constituent is $W_{\frac{3}{2}}O_2Ca$, the vertically acting $W_{\frac{3}{2}}O_2$; in lead molybdenate the horizontally acting component is $Mo_{\frac{3}{2}}O_2Pb$, the vertically acting $Mo_{\frac{3}{2}}O_2$. On this supposition we find :—

$$W_{\frac{3}{2}}O_2Ca, \quad d_1 = 5\cdot388, \quad v_1 = 24\cdot74.$$
$$Mo_{\frac{3}{2}}O_2, \qquad d_2 = 6\cdot685, \quad v_2 = 23\cdot13.$$

The sum of the partial volumes is 47·87, and the volume of the whole salt is 48.

$$Mo_{\frac{3}{2}}O_2Pb, \quad d_1 = 9\cdot775, \quad v_1 = 30\cdot88.$$
$$Mo_{\frac{3}{2}}O_2, \qquad d_2 = 3\cdot989, \quad v_2 = 24\cdot07.$$

The sum of the volumes is 54·95, and the volume of the whole salt is 54.

Calomel is a difficult mineral to treat, since the refractive equivalent of the mercury in it is abnormal. Taking as the

probable value 32, we may suppose the arrangement of atoms in the crystal to approach to Hg–Hg acting equatorially, and Hg–Cl acting vertically, we then obtain :—

$$Hg_{\frac{1}{2}}, \qquad d_1 = 10, \qquad v_1 = 10.$$
$$Hg_{\frac{1}{2}}Cl, \qquad d_2 = 4\cdot99, \quad v_2 = 26\cdot9.$$

The sum is 36·9, the volume of calomel is 36·3.

Numerous other compounds have been examined, with interesting and confirmatory results ; but we must content ourselves here with a single example, the most interesting, however, of them all. This is potassium copper chloride, $CuCl_2$, $2KCl$, $2H_2O$, the refractive indices for the line B are $n_\omega = 1\cdot6365$, $n_\epsilon = 1\cdot6148$.

It is obvious that no constitutional formula can be devised for this salt, without invoking a higher valency for some of the elements than they commonly possess. But this is a difficulty with which chemists are familiar in a large number of other cases, nor need it surprise us if in the solid state an element should exercise more numerous bonds than in the liquid or gaseous states ; it were rather to be expected. There are more ways than one in which the components of this hydrated potassium copper chloride can be built together into the complete molecule : we may choose as the simplest the following :—

Horizontal Plan.	Vertical Elevation.

```
   Horizontal Plan.              Vertical Elevation.
         H                             K
         |                             |
        Cl                             O
         |                             |
  H—Cl—Cu—Cl—H                  H—Cl—Cu—Cl—H
         |                             |
        Cl                             O
         |                             |
         H                             K
```
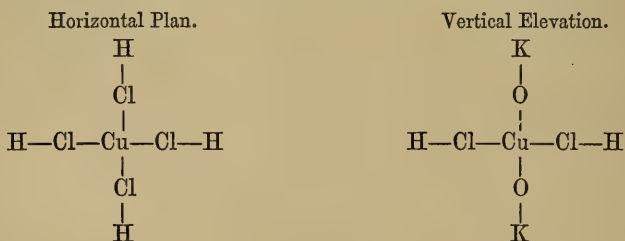
The atom of copper may be regarded as placed at the node of a tetragonal crystal-net, then on four rectangular ranges lying in a plane at right angles to the optic axis are the groups of –Cl–H, on two vertical ranges corresponding to the optic axis are the two groups –O–K ; acting vertically we shall then have the constituent $Cu_{\frac{1}{6}}$–O–K, which will be related to the index for the extraordinary ray, and acting horizontally $Cu_{\frac{1}{6}}$–Cl–H, which will be related to the ordinary ray.

Taking the following equivalents, $Cu_\Lambda = 11.72$, $Cl_\Lambda = 11$, $K_\Lambda = 8.2$, $H^\Delta = 1.3$, $O_\Lambda = 2.8$, we have $\Sigma_\Lambda = 82.72$; and for molecular weights, $Cu_m = 63.18$, $Cl_m = 35.37$, $K_m = 39.03$, $O_m = 15.96$, $H_m = 1$, we have $\Sigma_m = 318.64$ and $82.72 / 318.64 = 0.2596 = \kappa$; also

$$1.6311 \times 2 + 1.6070 / 3 = 1.6231 \text{ and } \frac{1.623 - 1}{2.4} = 0.2596 = \kappa.$$

Then for

$Cu_{\frac{2}{3}}ClH$, $\Sigma^\Delta = 14.253$, and $\Sigma_m = 46.9$, and $\dfrac{\Sigma_\Lambda}{\Sigma_m} = 0.3032 = \kappa_1$

(n_ω) $1.6311 - 1 / 0.3032 = d_1 = 2.081$, and $46.9 / 2.081 = v_1 = 22.53$.
Also for

$Cu_{\frac{2}{3}}OK$, $\Sigma_\Lambda = 12.953$, $\Sigma_m = 65.63$, and $\dfrac{\Sigma_\Lambda}{\Sigma_m} = 0.1974 = \kappa_2$

(n_ϵ) $1.6070 / 0.1974 = d_2 = 3.025$, and $65.63 / 3.025 = v_2 = 21.42$.
Finally,

$v_1 \times 4 = 90.12$, and $v_2 \times 2 = 42.84$, and $90.12 + 42.84 = 132.9$.
But $318.64 / 2.4$ (the density of the salt) $= 132.8$.

There is thus between the sum of the volumes of the components and the value of the volume of the whole salt a correspondence almost exact.

The special interest of the salt lies, however, in the fact that it is dichroic, displaying a green tint when illuminated by the ordinary ray, and a sky-blue when seen by the extraordinary ray. If our hypothesis have in it any truth, then this difference in tint should be correlated with the difference in chemical constitution which we have imagined to exist in the direction of the vertical and horizontal crystallographic axes. Let us see. Along a vertical range lies Cu_3OK; this gives for the copper-oxygen compound, $Cu_{\frac{2}{3}}O_{\frac{3}{2}}$, or CuO_3;[1] along a horizontal range, $Cu_{\frac{2}{3}}Cl_{\frac{3}{2}}$, or $CuCl_3$;[1] evidently the copper acting vertically is more of a cupric nature than that acting horizontally, but cupric salts are characteristically blue, and cuprous salts are as commonly green in colour. Thus the correspondence predicated actually exists, and in stumbling on this confirmation of our hypothesis we have discovered a theory of pleochroism. The commonest pleochroic

---

[1] Of course these are impossible compounds, and are only to be regarded as shadowing forth the true relations, which are more fully discussed in the Memoir.

minerals are those containing iron or manganese as constituents, and it sometimes happens that a silicate which, when containing a small quantity of iron (as what is commonly called an impurity), is pleochroic, loses the pleochroism when the ferruginous impurity is absent. If then we have a ferrous constituent acting in one direction, and no ferruginous constituent in another, the mineral may be colourless in the latter, and green in the former direction. If there exist a ferrous in one direction, and a ferric constituent in another direction, the salt may be expected to be green in the former, and yellow or reddish in the latter direction. Other cases will naturally suggest themselves.

Although this paper is only an abstract of the detailed Memoir, I cannot let the opportunity pass of thanking my friends who have helped me with their criticisms and advice in this inquiry. Dublin is fortunate in possessing a number of distinguished physicists—I need only mention Professors Fitzgerald and Preston, and Doctors Johnstone Stoney, Joly, and Trouton, from all of whom I have received great help in discussion, but chiefly from Professor Fitzgerald, without whose encouragement the investigation, which was commenced some four or five years ago, would never have been completed.
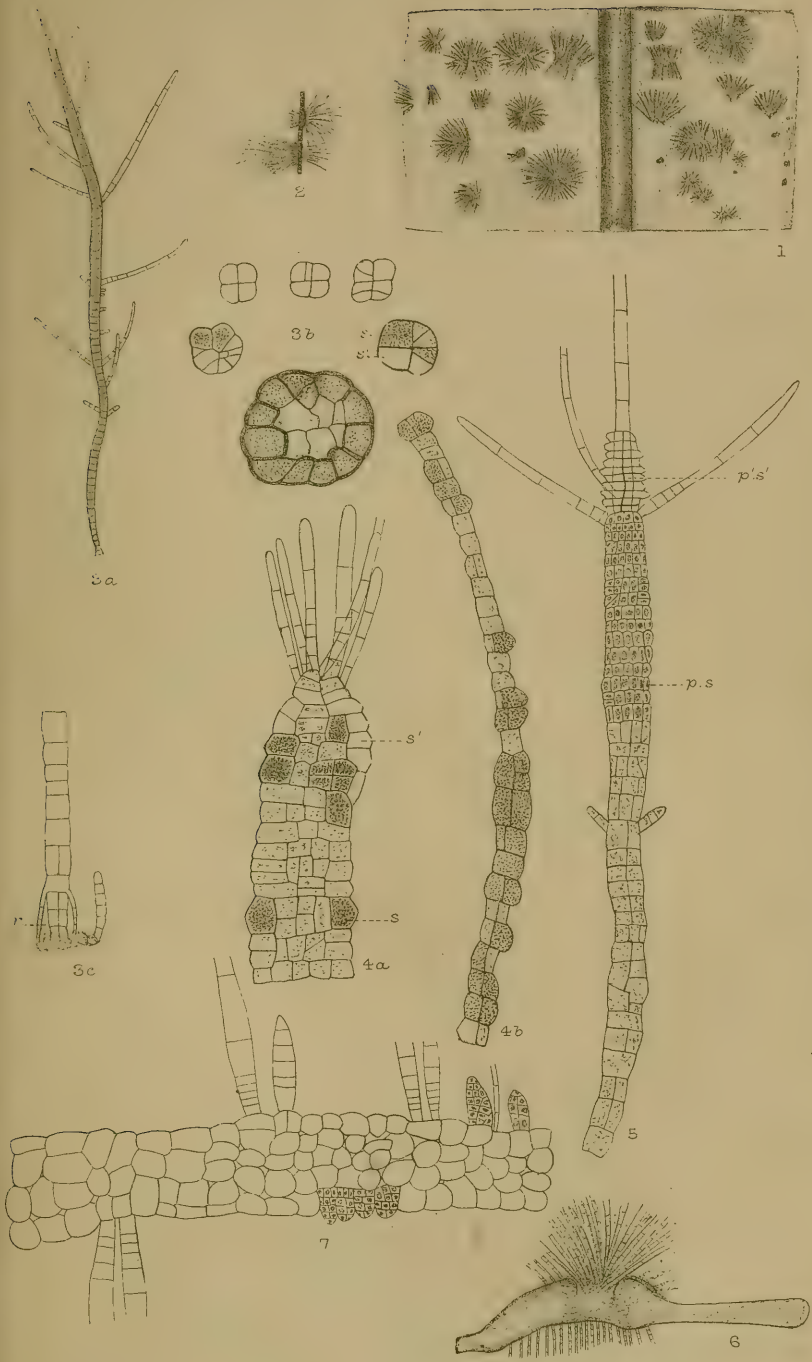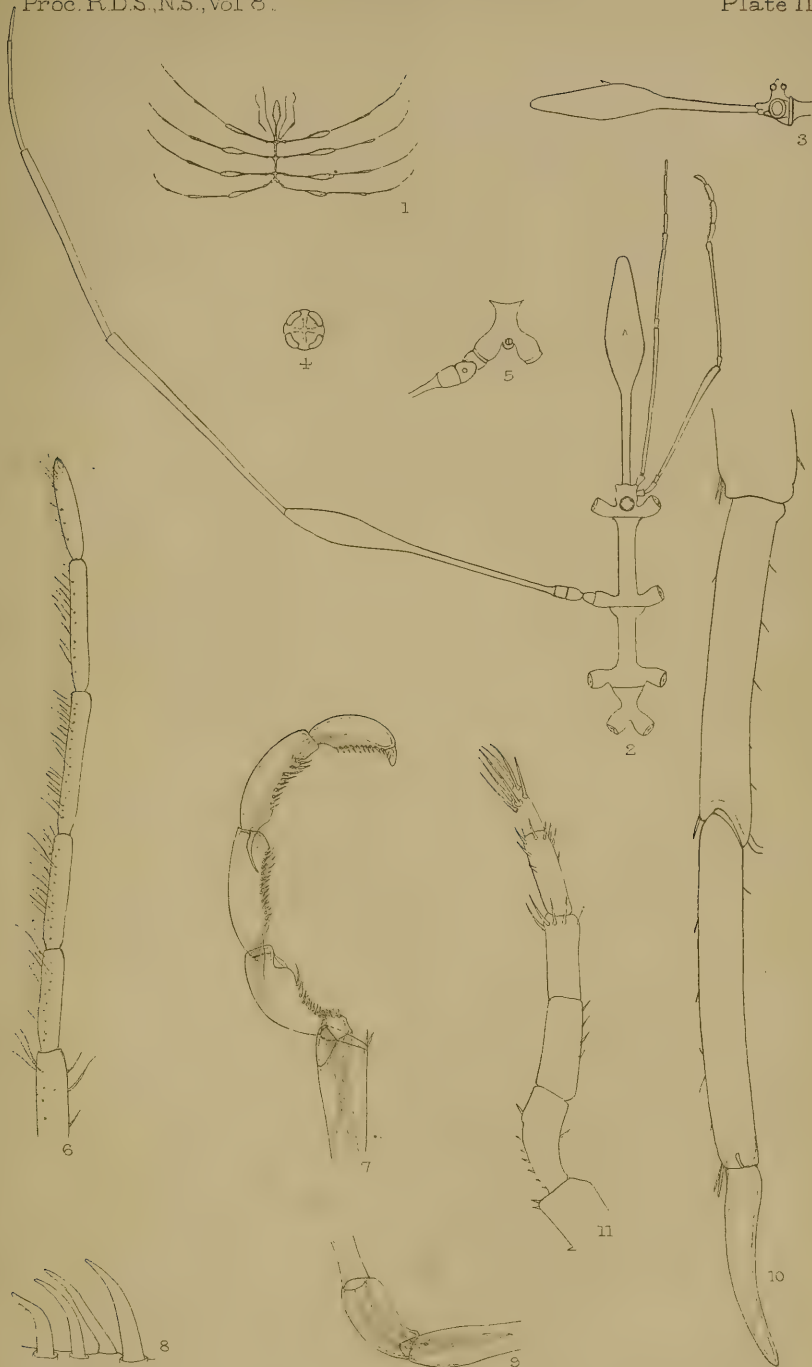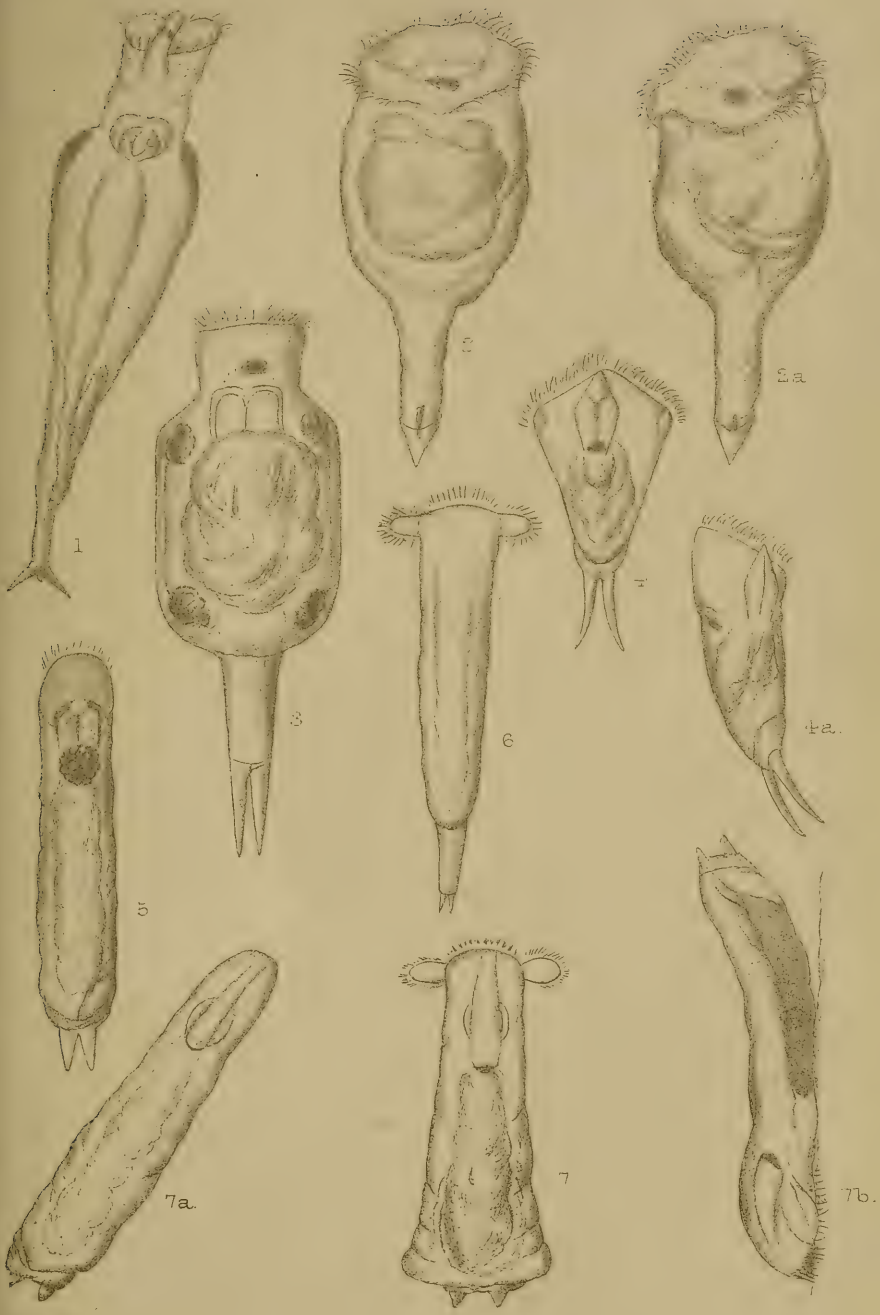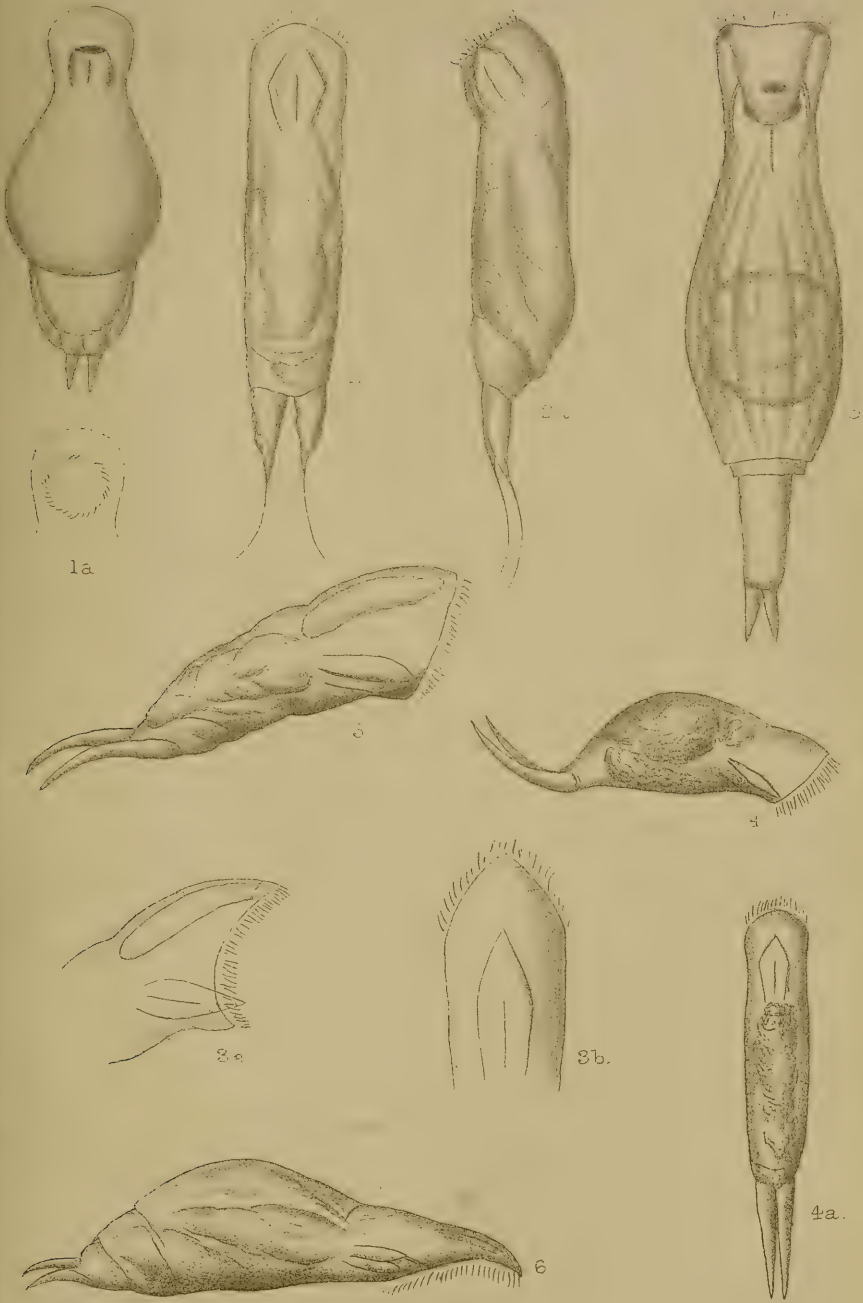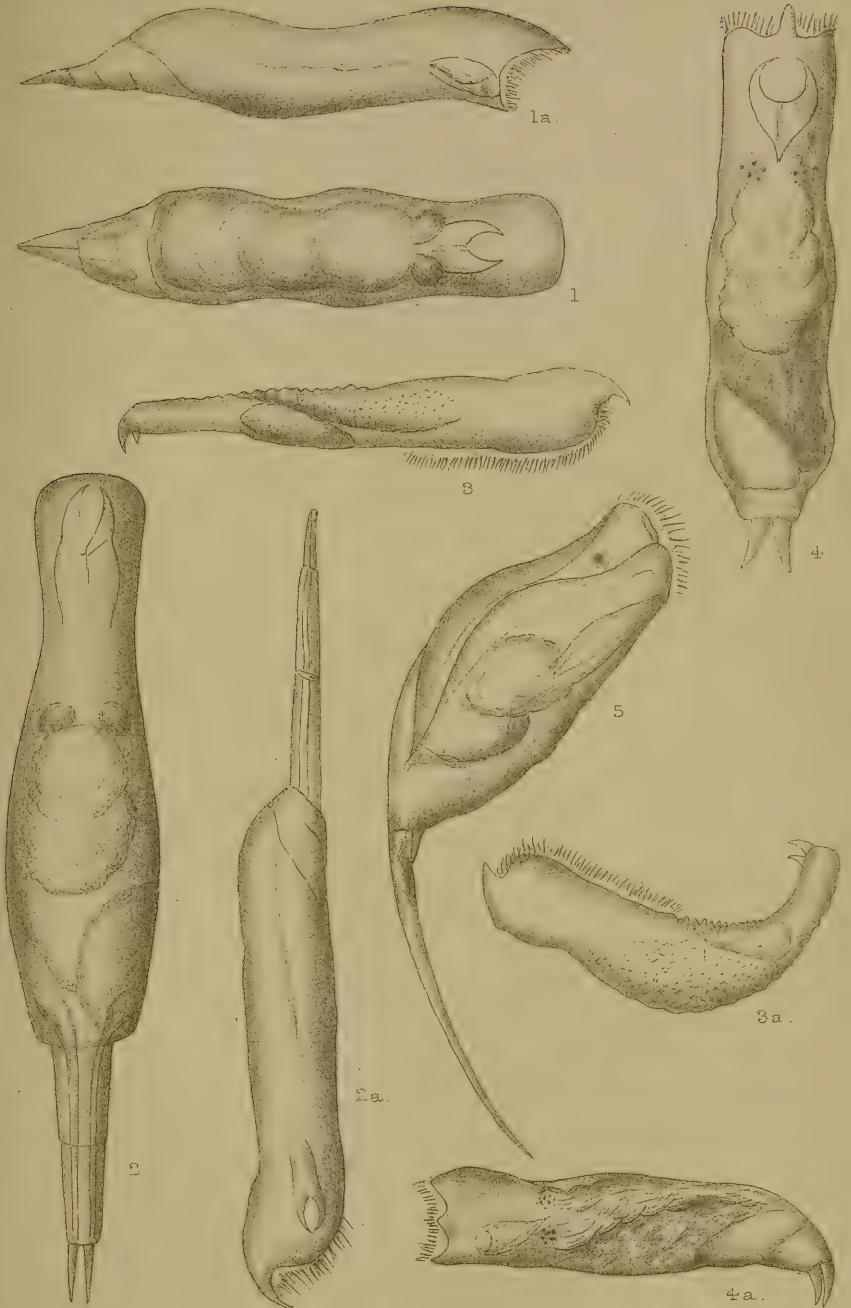
Plate I.

Plate II.

Plate III.

L.S.G. del.

West,Newman.lith.

Irish Rotifers.

1a

2a

3

4

3a

3b

4a

6

Irish Rotifers.

Plate V.

L.S.G.del.

West, Newman lith.

Irish Rotifers.

Plate VI.

Irish Rotifers.

Irish Rotifers.

1   × 20   2   × 50

3   × 8
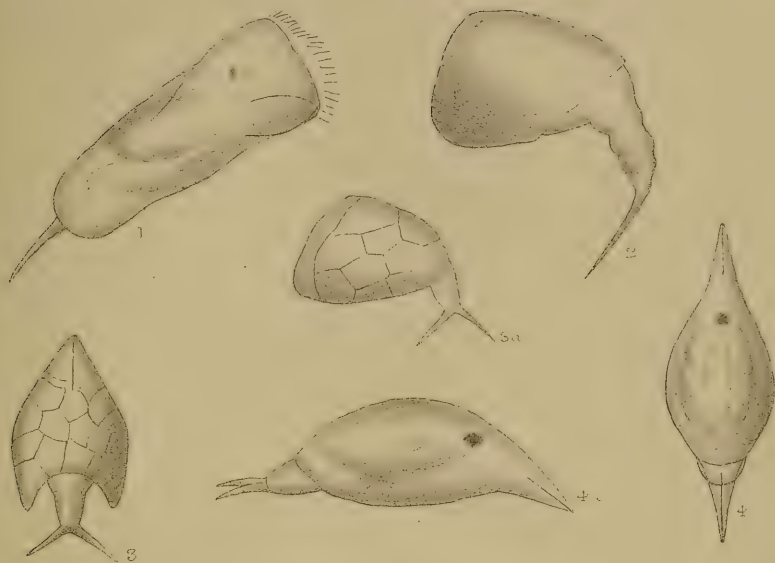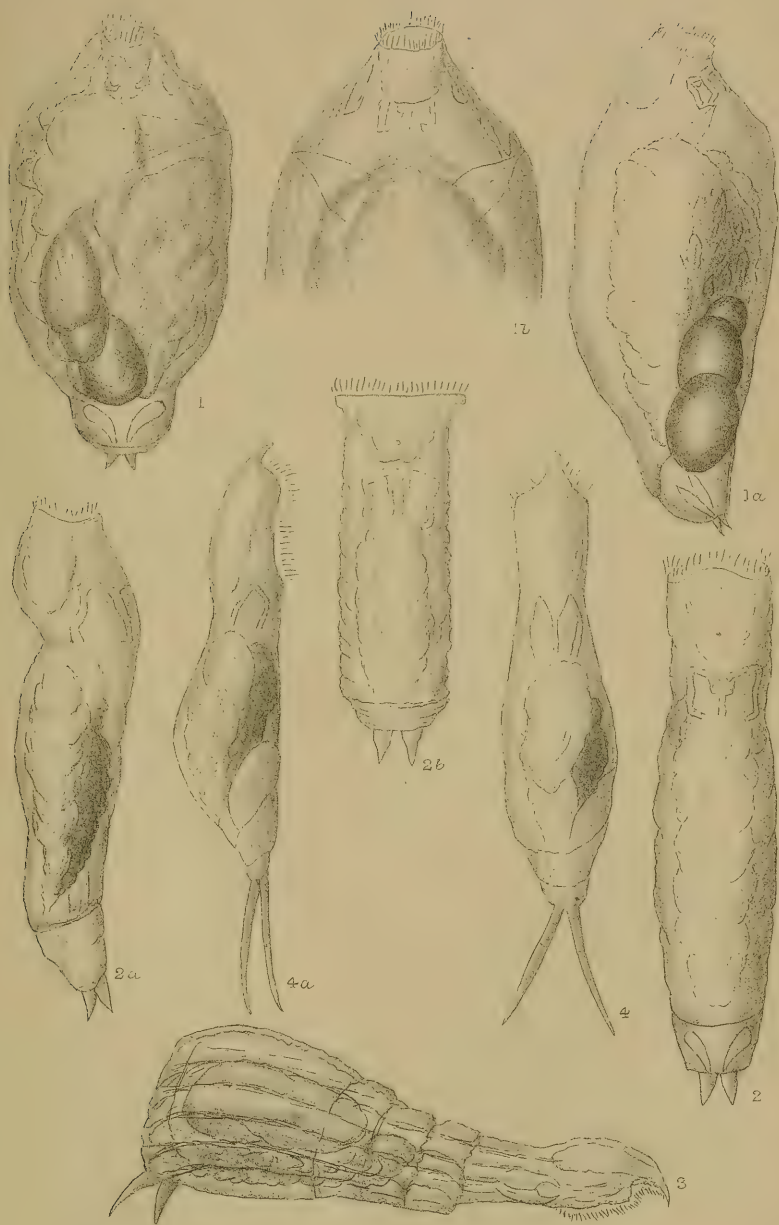
5   nat.size.   4   × 4

Hemitrypa hibernica.

THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

Vol. VIII. (N. S.)   SEPTEMBER, 1893.   Part 2.

CONTENTS.

PAGE

XIV.—A Lecture Note on the Relation of the Theorem of Work to the Theorem of Moments. By THOMAS PRESTON, M.A., F.R.U.I., 167

XV.—Report on Polychæts collected during the Royal Dublin Society's Survey off the West Coast of Ireland. Part I. Deep Water Forms. By FLORENCE BUCHANAN, B.Sc., Univ. College, London. (Plates IX., X., XI.), ... 169

XVI.—Notes on *Depastrum cyathiforme*. By G. Y. and A. FRAS. DIXON, ... 180

XVII.—On a Photographic Method of detecting the Existence of Variable Stars. By J. JOLY, M.A., Sc.D., F.R.S., . . . 184

XVIII.—On the Distortion of Photographic Star Images due to Refraction. By PROFESSOR ARTHUR A. RAMBAUT, M.A., D.Sc., . 186

XIX.—On some Pycnogonida from the Irish Coasts. By GEORGE H. CARPENTER, B.Sc., Lond., Assistant Naturalist in the Science and Art Museum, Dublin. (Plate XII.), ... 195

XX.—On a Graphitic Schist from Co. Donegal. By RICHARD J. Moss, F.C.S., F.I.C., ... 206

The Authors alone are responsible for all Opinions expressed in their Communications.

DUBLIN:

PUBLISHED BY THE ROYAL DUBLIN SOCIETY.

LONDON: WILLIAMS & NORGATE, 14, HENRIETTA-STREET, COVENT GARDEN.

1893.

Price One Shilling and Sixpence.

Royal Dublin Society.

EVENING SCIENTIFIC MEETINGS.

The Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and ready for transmission to the Editor.

XIV.

A LECTURE NOTE ON THE RELATION OF THE THEOREM OF WORK TO THE THEOREM OF MOMENTS. By THOMAS PRESTON, M.A., F.R.U.I.

THE moment of a force with regard to any point (being the pro-duct of the force and the distance of the point from its line of action) is clearly of the same dimensions as work, and consequently the theorem of moments, which states that the moment of the resultant of two (or more) concurrent forces is equal to the sum of the moments of the forces, must be in some way related to, if not identical with, the theorem of work which states that the virtual work of the resultant in the same case is equal to the sum of the virtual works of the component forces. It is undoubtedly impor-tant that students should have the relation between these theorems pointed out to them at the beginning of their course, so that they may have a clear grasp of the principles which they afterwards employ in so many departments, and a full knowledge of the ground on which each rests, and of how far they overlap each other, or are altogether independent.

I have consequently been induced by these considerations to bring under your notice the following lecture note concerning the relation of the theorem of work to the theorem of moments. This relation will appear evident at once if we remark that the work done by any force OX, during any displacement OP, is equal to the moment with re-gard to P of an equal force OY drawn through O at right angles to OY. For the work of OX, when O is displaced to P, is $OX \cdot OM$, and the moment of OY with regard to P is $OY \cdot PN$,

Fig. 1.

and these are obviously equal since we have taken $OY = OX$, and PM and PN are drawn at right angles to OX and OY respec-

tively. We have then the general elementary theorem that the work of a force is equal to the moment of an equal perpendicular force. Hence if we take the case of two forces OP and OQ, and their resultant R, forming the sides and diagonal of a parallelogram, and if three others OP', OQ', OR', be drawn at right angles to them, and equal to them respectively; then if O be displaced to O' the works of the forces OP, OQ, OR, will be equal to
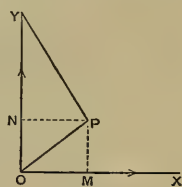
Fig. 2.

the moments of OP', OQ', OR', respectively, with regard to the point O'; but since $OP'Q'R'$ is a parallelogram, it follows that the moment of R' is equal to the sum of the moments of P' and Q'; therefore the work of R is equal to the sum of the works of P and Q.
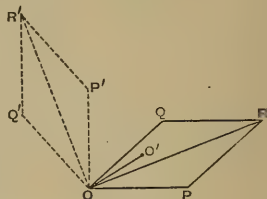
By some such demonstration as this I think the beginner might be shown how these two theorems are related, and that when the theorem of moments is established the theorem of work follows as a corollary; or, in fact, when it has been shown that the triangle, having the diagonal OR of a parallelogram for base, and any point as vertex, is equal to the sum of the triangles having the same point for vertex, and the sides OP and OQ for bases, then we may write down as corollaries to this geometrical theorem—(1) the theorem of moments; (2) the theorem of work; (3) the theorem (or parallelogram) of angular velocities, the latter following from the fact that, if a body rotates round any axis OP with an angular velocity measured by OP, then the velocity of any point O' will be measured by the product of OP and the perpendicular from O' on OP, that is, by the moment of OP with regard to O'. Similarly the velocity of O' due to a rotation round OQ will be equal to the moment of OQ, and the sum of these is equal to the moment of OR; therefore, &c.

XV.

REPORT ON POLYCHÆTS COLLECTED DURING THE ROYAL DUBLIN SOCIETY'S SURVEY OFF THE WEST COAST OF IRELAND. PART I. DEEP WATER FORMS. By FLORENCE BUCHANAN, B.Sc., Univ. College, London.

(Plates IX., X., XI.)

THE collection of Polychæts on which I am about to report was kindly made over to me, for the purpose of identifying the species in it, by Professor Haddon after the survey of 1891. Although small it has proved to be of some interest. Only three families, namely, the Aphroditidæ, the Eunicidæ, and the Serpulidæ, appear to be represented in that part of the collection obtained from deep water. There is also a tube of a Terebellid. There are seven different species, of which one is new, and of which one has apparently not been recorded before, except in the neighbourhood of the far-off Island of Kerguelen.

Fam.—Aphroditidæ.

I.—Lætmatonice producta, Gr.

There are four good specimens of this species dredged from a bottom of sand and gravel at a depth of 500 fathoms 54 miles off Achill Head. There is no mistaking the species, as it agrees both with Grube's[1] and M'Intosh's[2] description; but it is curious that, as far as I am aware, it has only as yet been recorded in the South Seas near Kerguelen, though in that region it is apparently

---

[1] Grube, Monatsberichte d. k. Akad. d. Wiss. z. Berlin, 1877, p. 512.
[2] M'Intosh, "Challenger Report" xii., p. 39, Pl. viii. and iv., Af. 1–8.

abundant. That it does occur elsewhere, although unrecorded, I can witness from a specimen of it in the British Museum (which was labelled "Lepidonotus") coming from Japan. At Kerguelen both it and its varieties seem not to have been found below a depth of 120 fathoms. The Japan specimen was dredged at a depth of 43 fathoms. Perhaps it is due to the fact that the Irish specimens come from a so much greater depth that, although they have well-developed eye tubercles, they have no eyes. The only other points besides the absence of eyes in which the Irish specimens differ from the Kerguelen ones are that there are not quite so many segments (43 or 44 instead of from 44–47), and that there is a great deal of individual variation with regard to the length and size of the palps on the two sides of the body, sometimes the left, sometimes the right, being the larger, but in no specimen being quite equal in size. The median tentacle was only complete in one specimen. It is very fine and delicate, and a little over half the length of the longer of the two palps in this specimen. The so-called "glochidial" setæ on the elytra-bearing segments were broken off in most of the specimens, but such as there were resembled the one figured by M'Intosh in shape.

II.—Lætmatonice filicornis, Kbg.

There is one specimen which I think is to be referred to this species, though it differs in one point from Kinberg's description[3]; it was dredged at a depth of 500 fathoms 45 miles off Blackrock on a bottom of sand and gravel. A good deal of confusion obtains between the species *filicornis*, Kbg. and *Kinbergi*, Baird, some authors, *e.g.* Malmgren[4] and M'Intosh,[5] regarding them as identical, others, *e.g.* Ehlers,[6] being inclined to regard them as distinct species, the difference being that, while in *L. filicornis*, Kbg. the median tentacle is longer than the palps, and the ventral setæ have no spine below the feather-like tuft at their extremity,

---

[3] Kinberg, K. Sv. "Freg. Eugenies Resa," Zool. II. Annulater, p. 7, pl. iii. f. 7, *a–h*.

[4] Malmgren, Ann. Polych., p. 3.

[5] M'Intosh, Trans. Roy. Soc., Edin., vol. xxv. Pt. II., 1868–9, p. 407.

[6] Ehlers, "Results of Dredging off the U. S. Coast Survey Steamer 'Blake.'" "Report on the Annelids," p. 44, pl. vii., f. 6, and viii., f. 1–5.

in *L. Kinbergi*, Baird, on the other hand, the tentacle is *shorter* than the palps, and there *is* a spine to the ventral setæ.

In the specimen in the Irish collection the median tentacle is long and very slender, but it is still only about half the length of the palps. The ventral setæ, such as are complete (a great many were broken at the tips when I received the specimen), show mostly no trace of a spine. One or two, however, did show a sort of rudimentary or (?) broken spine. I have figured both kinds of setæ on Pl. IX., fig. 1 (A. and B.). The specimen seemed to me, therefore, to be intermediate between the two so-called species in question, and I was inclined to agree with Malmgren and M'Intosh that they were one. But then another difficulty arose. Ehlers is, I believe, the only writer who mentions on which segments the elytra occur. In his *L. Kinbergi* they are on segments 2, 4, 5, 7, ... 23, 26, 29. In the specimen I had before me they are on segments 2, 4, 5 7, ... 23, 25, 28, 31. Hoping to throw some light on the question I went to the British Museum to examine Baird's original specimens of *L. Kinbergi*, and what specimens there are of *L. filicornis* with regard to the three points at issue: the length of the tentacles, the spine of the ventral seta, and the position of the elytra. In all the specimens, both of Baird's *L. Kinbergi* (of which there are a large number, all from the North Sea off the Shetlands[7]) and of those labelled *L. filicornis*, where the median tentacle is still present, it is shorter than the palps, being from ⅓ to ½ their length. Taking several of Baird's *L. Kinbergi* at random, and examining their ventral setæ, I was surprised to find that the greater number of these on most specimens had no spines (fig. 1 A.); sometimes there were some with rudimentary spines (fig. 1 B.) beside those with none, but only on a few specimens did I find well-developed spines on the ventral setæ (fig. 1 C.),

---

[7] I may as well mention here that in the bottle labelled *L. Kinbergi*, by Baird, there are present besides the Lætmatonices a good number of specimens, looking at first sight not unlike them, which are not Lætmatonices at all, but which are really the *Aphrodite obtecta* of Ehlers (*loc. cit.* p. 42, pl. vi.), so that the specimen which I obtained at Plymouth, and mentioned in my Report to the British Association last year as being found for the first time on British Coasts, was not really new to Britain, though it had not been recorded before.

It is owing to the kindness of the authorities of the British Museum that   am able to comment on the specimens there; and I should like here to express my thanks for the facilities that have been given me.

but when present at all they seemed to form the larger number of the setæ, there being only a few with no spines or only rudimentary ones besides them. In all the other different specimens labelled *L. filicornis* that I examined the spines were well developed. Only in the " Challenger" specimen, where very few ventral setæ remained, these had rudimentary spines only. All this tends to confirm M'Intosh's view that there is but one species varying individually with regard to the spines on the ventral setæ and probably also with regard to the relative lengths of palps and tentacle, although, as far as I know, it is only Kinberg's original specimens which have the tentacle longer than the palps. When, however, I proceeded to count the elytra I found that on all the specimens I examined, and I examined a good many of both *L. Kinbergi* and *L. filicornis*, they were placed, as in the Irish specimen, on segments 2, 4, 5, 7, ... 23, 25, 28, 31. I am therefore led to conclude that only one species has as yet been found in British Seas. This we may call *Lætmatonice filicornis*, Kbg. The relative length of the tentacles and palps may vary, though the tentacle is usually shorter than the palps[8]; there may or may not be a spine to the ventral setæ (or possibly the presence of a large number of spined setæ may be a sexual character acquired at certain times of year); the elytra are always on segments 2, 4, 5, 7, ... 23, 25, 28, 31. To this species I should be inclined to refer the *L. violascens* of Grube,[9] as there are in the British Museum (in the same bottle as Baird's *L. Kinbergi*) several specimens with a distinct violet tinge to their elytra, which I believe to be the same as the one specimen from which Grube described his species. Many of these, like Grube's specimen, have no felty covering[10]; the palps vary in length, but the tentacle is usually a good deal shorter. The ventral setæ mostly, but not entirely, have well-developed spines. The elytra are as in the other specimens with regard to their arrangement, and I should consider their colour

---

[8] The palps do occasionally vary in length on different sides of the body here as in *L. producta*, though not to so great an extent. This variation shows how little one can rely in this instance on the relative lengths of the head appendages in fixing the species.

[9] Jahresbericht d. Schlesischen Gesellschaft, for 1874, p. 65.

[10] The Irish specimen also had no felty covering over its back, though it had what appeared to be the remains of it at the sides of the body. Grube himself calls attention to the fact that the felty covering is not always present in *L. filicornis*.

either as an individual variation (sexual or otherwise), or possibly as allowing them to rank as distinct variety, though not as a distinct species. From this species *L. filicornis* (including the *L. Kinbergi* of Baird and the *L. violascens* of Grube) we must distinguish another species for the *L. Kinbergi* of Ehlers, the chief specific difference being that the elytra are on segments 2, 4, 5, 7, . . . 23, 26, 29. Whether the *L. armata* of Verrill[11] belongs to this species, as Ehlers suggests, or to *L. filicornis* must remain undecided, as it is not stated to which segments the elytra are attached.

Fam.—Eunicidæ.

III.—Eunice philocorallia, n. sp.

A Eunice, presenting a good many individual variations, but which I have not been able to refer to any known species, occurred abundantly in parchment-like tubes, inhabiting colonies of *Lophohelia prolifera*. I give as its specific diagnosis the following :—

Body light in colour, and iridescent, arched on the dorsal surface, tapering posteriorly. Prostomium bearing five tentacles, varying greatly in length in different individuals and with regard to one another in the same individual, but generally long, the median one being usually the longest, and reaching back over about eight segments. Palps divided by a groove each into a small median and a larger lateral lobe. One eye on each side at the base of the external tentacle. First (peristomial) segment nearly as broad as the four following ones. Second segment sharply marked off from it, except at the sides, bearing two long, smooth tentacular cirri, generally reaching beyond the palps even, though frequently varying in length on the different sides of the body. Third segment with well-developed dorsal and ventral cirri, but parapodial lobe minute and with very few setæ. Parapodia on all the other segments consisting of one well-developed lobe bearing a dorsal and ventral cirrus; dorsal cirrus long, unjointed, filamentous; ventral cirrus filamentous, and about one-third the length of the dorsal in the first four segments, after that short and blunt, swollen at the base; dorsal setæ both capillary

---

[11] Verrill, Proc. U. S. Nat. Mus. ii., 1879, p. 168.

and chisel-shaped; ventral setæ compound, the appendage with two hooks; acicles two anteriorly, but posteriorly sometimes as many as five (three dorsal and two ventral). Branchiæ beginning on the ninth segment (seventh parapodia), with one, two, or three filaments, present on all the following segments, until very near the posterior extremity of the body, but with never more than four filaments, which are from a quarter to half the length of the dorsal cirri, and arranged in a small comb. Two anal cirri. Maxillæ with six teeth each side, or with only five on the left; unpaired Sägeplatte with six teeth, paired with four on the left side, eight on the right.

No. of segments, 110–152; length, 120–190 mm.; breadth, 6·5–8 mm.; length of each of first three segments, 0·8–1 mm.; length of following segments, 1·3–1·8 mm.

Tubes of a parchment-like consistency, with jagged lateral openings. Found inhabiting colonies of *Lophohelia prolifera*, dredged at a depth of 200 fathoms, fifty miles off Bolus Head, Kerry.

The various points are illustrated, and some of the individual differences shown in the figures, Pls. IX. & X., figs. 2–8. The figure on Pl. XI. shows the relation between the worm and the coral. Apparently the worm is commensal on the coral, and to some extent modifies its growth, the coral growing round the worm-tube which thus becomes embedded in the cœnenchyme. I have often seen parts of colonies of *Lophohelia prolifera* with hollow tubular cavities similar to those we have here, and it seems very probable that they are likewise due to the presence of worms, although, as far as I know, no worm has as yet been described as taking up its abode in this particular coral.[12] It would be interesting to know the nature of the worm, if present, inhabiting colonies from other localities. With regard to the one before us, I may call special attention to one specimen (Pl. IX., fig. 4), in which there are two tentacular cirri on the right side in the second segment, instead of one (the left tentacular cirrus happens to be broken rather near its base in this specimen). Instances of such duplication, or even

---

[12] Other worms have been described on other corals; and different crustaceans, as is well known, frequently cause modifications in the growth of coral. The subject is dealt with by Semper in his "Natural Conditions of Existence as they affect Animal Life."

triplication, of organs on one side are not uncommon in Polychæts. Both Ehlers[13] and Quatrefages,[14] for instance, mention the occurrence of the same thing in *Eunice gigantea.* M'Intosh[15] mentions it in a Nothria. I have also occasionally noticed the duplication of an ordinary dorsal cirrus on one side in *Eunice gigantea* and other polychæts. Perhaps the most striking example I have seen of the duplication of an organ on one side is in a Chlœia in the Royal College of Surgeons Museum, where there is a second perfect branchia smaller and nearer the dorsal median line than the ordinary one, on one side (the left), near the posterior extremity of the body (twenty-eighth segment). The branchiæ of Chlœia, being somewhat complex structures, this duplication is more remarkable than that of simple structures like cirri.

The species would seem to be most nearly allied to the *E. floridana* of Ehlers,[16] but differs from it in the greater length of the dorsal cirri and in the possession of a smaller number of branchial filaments, also somewhat in the shape of the maxillæ.

There were three small Eunices, one of only 20 mm. in length in the coral itself, another of about 30 mm. in the same bottle with the coral, and the third, of 36 mm., in a red serpulid tube, dredged with the coral. These I take to be the young of *Eunice philocorallia.* The jaws have the same six teeth each side, and are in other ways much alike. In the smallest specimen there is only a single filament to each branchia (except on a few segments here and there, where there are two), and this is almost as long as the dorsal cirrus in some segments. The same variation in the length of the tentacles occurs as in the adults, the right inner lateral tentacle being a good deal longer than the median or than any of the other tentacles. In the same way, the right tentacular cirrus of the second segments is longer than the left. In the other two specimens the branchiæ, except in the first few segments after their appearance at all, have two filaments, and occasionally even three. I have figured the head and one parapodium of the largest of these three specimens (Pl. x., figs. 8 and 9).

---

[13] Ehlers, " Borstenwürmer," p. 311.

[14] " Quatrefages," Annélés, vol. i., p. 312.

[15] M'Intosh, " Challenger Report," xii., p. 328.

[16] Ehlers " Report on Dredging, &c.," *loc. cit.* p. 88, pl. xxii.

In a species in which so many individual variations occur, it is curious that the branchiæ should begin so regularly on the 9th segment on each side, as this is one of the points most liable to variation in the Eunicidæ. Only in two specimens (one young and one adult) did I find the branchiæ beginning on the 10th instead of on the 9th segment on one side of the body.

With regard to the tentacles, although not annulate as a rule, apparent annulation occasionally occurs in one or other of the tentacles of the adult (*cf.* Pl. ix., fig. 2); and in two of the young specimens there are faint traces of annulation. It seems to me doubtful whether so much importance should be attached to the annulation of the tentacles, as Grube does for instance in his Revision of the Eunicidæ in the Jahresb. Schles. Gesellsch. for 1877. Ehlers draws attention to the variation in individuals with regard to this point for *E. rubrocincta.*[17] The same may be said for the dorsal cirri (*cf.* fig. 7*a.*)

<center>Fam.—SERPULIDÆ.</center>

<center>(*a.* Serpulidæ proper.)</center>

IV.—**Serpula Philippii**, Mörch. (*Serpula vermicularis*, Phil.).

Two specimens of this fairly-common species[18] occurred with the *Lophohelia prolifera* above mentioned. In both of them the well developed operculum is on the left side, the rudimentary on the right.

A third specimen, which I think is referable to this species, was dredged 45 miles off Blackrock, at a depth of 275 fathoms. It only differs from *S. vermicularis* as usually described, in having eight instead of seven thoracic bundles of setæ. Variations with regard to the segments between which the change of setæ takes place do, however, occur in other members of the family (*e. g.* *Sabella viola*, Grube, A. f. N. Jahrg. 29. 1863, p. 58). In this specimen the well-developed operculum is on the right side, the rudimentary one on the left.

---

[17] Ehlers. "Borstenwürmer," p. 345.

[18] Perhaps the best figure of the species extant is the one given in Cuvier's "Règne Animal." Annelides (Edition acc. de Planches), pl. iii. fig. 1, under the name of *S. contortuplicata.*

V.—**Hydroides pectinata** (Kuppf.) v. Mrzllr. (= *H. norvegica*, Gunn. and *Eupomatus trypanon*, Clp.)

Several specimens of this species occurred, all attached to the spines of *Cidaris papillata*, dredged both 40 miles off Achill Head, at a depth of 220 fathoms, from a bottom of fine sand, and 45 miles off Blackrock, at a depth of 275 fathoms, from a rocky bottom. Claparède[19] also mentions it as occurring on the spines of Cidaris. The number of pairs of teeth to each spine of the operculum is not necessarily limited to two, as Claparède seems to imply, and there may be as many as sixteen spines to the operculum.

(*b.* Sabellidæ.)

VI.—**Dasychone Savignii**, Johnst.

There is one specimen which I venture to refer to this species, because as far as Johnston's description[20] goes it agrees with it, and because the *Dasychone argus*, Sars (the *D. Dalyelli*, Köll.), to which Malmgren[21] refers it with a query, differs from it in having eyes on the branchiæ. My specimen, like Johnston's, has no eyes on the branchiæ, and also, like Johnston's, the branchiæ are longer in proportion to the body than they are in the *Dasychone argus* or the *D. lucullana* of Sars, to one of which species the *Sabella (D.) bombyx* of Johnston, from which he distinguishes his *S. (D.) Savignii*, probably belongs. (Malmgren unites all three species; Carus[2] distinguishes two species—the *D. lucullana* of Delle Chiaje and Sars, and the *D. polyzonos*, Panc., including *D. Dalyelli*, Köll., and *D. argus*, Sars, but does not say to which he would refer Johnston's *D. bombyx*). For the sake of clearness I have figured my specimen (figs. 10–12), and subjoin a specific diagnosis.

Dasychone,[23] with branchiæ more than half the length of the

---

[19] Claparède, Ann. Chæt. d. G. d. Naples Suppl. p. 527, pl. xiv., f. 4.

[20] Johnston, "Catalogue of Worms in the Brit. Mus.," p. 261.

[21] Malmgren, Nordiska Hafs. Annulater Öfvers. af. K. Vet. Ak. Förh. 1865, p. 403, and Annul. Polych., *Ibid.* 1867, p. 241.

[22] "Carus. Faunæ Mediterraneæ," p. 272.

[23] It may be convenient to have the generic diagnosis at hand. I therefore quote the substance of that given by Carus:—Collar thin, divided into two halves; setigerous tubercles beginning on the collar segment, with winged capillary setæ, long and slightly curved at the apex; uncinigerous tori beginning in the second segment, each bearing a

body; filaments varying individually in length and not necessarily equal in number on both sides of the body (16.-19), richly barbed on the ventral side, but with very few, only two, or sometimes three, very short barbs on the dorsal side, and with no ocular spots. Prostomial tentacles lanceolate, one-third length of branchiæ. Change of setæ 8/9. Capillary setæ of thorax of two kinds. Dark spots between the setæ and tori extending nearly to the posterior end of the body through about the first thirty segments. On each ventral shield on either side of the middle line through the same segments there is also a dark spot.[24]

Number of segments, about 45. Length (without branchiæ) about 10 mm.; branchiæ, 6 mm.; breadth, 1·5 mm.

Tubes of closely adhering mud and fine sand. Locality, 50 miles off Bolus Head, 200 fathoms, " coral " bottom.

The specimen is not very complete, and I have had to " restore " it somewhat in figuring it. A peculiarity in my specimen is that the posterior end is bifid (Pl. x., fig. 10), but the anus apparently is between the two prongs, not as in Claparède's specimen of *Salmacina incrustans*,[25] also double.

I am not sure in how far I am justified in associating this with Johnston's species,[26] but think it will be less confusing than making a new species for a single and not quite complete specimen.

Fam.—Terebellidæ.

The tube of a Terebella, which is probably the *T. flabellum* of Baird[27] and M'Intosh[28] was dredged 40 miles off Achill Head at a depth of 220 fathoms.

---

single row of avicular uncini, everywhere of the same form. Branchiæ forming a semicircle somewhat convoluted at the base on each side, apex of each filament naked, short and subulate, bases connected to form a membrane, dorsal appendages to branchial filaments present, but short, arranged in pairs; ocular spots on the branchiæ in some species, not in others. A black spot on each side of the body between each torus and bundle of capillary setæ.

[24] The same thing occurs, judging from some Naples specimens, in *D. lucullan,* Sars and D. Ch.

[25] " Claparède," Ann. Choet. Pt. II., p. 177, pl. xxx., f. 5 F.

[26] Johnston's type specimen, as Malmgren has already observed, has now got no branchiæ, and would be very difficult to diagnose.

[27] Baird, Journ. Linn. Soc., VIII., p. 157, pl. v., figs. 1 and 2.

[28] M'Intosh, " Challenger Report," p. 447, pl. l., fig. 1.

EXPLANATION OF PLATES.

PLATE IX.

Fig. 1. Neuropodial setæ of *Lætmatonice filicornis*, Kbg.
    A and B, from the specimen in the Irish collection.
    C, from a specimen in the British Museum.

Fig. 2. Anterior extremity of *Eunice philocorallia*, n. sp. Dorsal view.

Fig. 3. Same (of another specimen), ventral view. The white part of the mandibles is seen projecting from the mouth.

Fig. 4. Dorsal view of the first three segments of another specimen, showing the double tentacular cirrus on the right side.

Fig. 5. Maxillæ.

Fig. 6. Mandibles.

PLATE X.

Fig. 7. Parapodia—
    a, of the third segment.
    b, of one of the middle segments.[29]
    c, of one of the posterior segments.

Fig. 8. Dorsal view of anterior region of a young *Eunice philocorallia*.

Fig. 9. Parapodium from about the middle region of the same.

Fig. 10. *Dasychone Savignii*, Johnst. Ventral view.

Fig. 11. Left side of anterior part of the body of the same to show the shape of the collar.

Fig. 12. Setæ of same.
    a and *b*, capillary setæ of thorax.
    c, uncinus.

PLATE XI.

Eunice philocorallia in *Lophohelia prolifera*, the coral broken so as to show the posterior extremity of the worm as well as the anterior. The parchment-like tube of the worm is also seen. This figure was kindly drawn for me by Mr. E. T. Brown of the Zoological Laboratory of University College.

---

[29] The branchiæ are not usually as long as they are in the parapodium here figured.

XVI.

NOTES ON *DEPASTRUM CYATHIFORME*.
By G. Y. and A. FRAS. DIXON.

Depastrum cyathiforme, Gosse.—We have found this rare
Lucernarian on both sides of Dalkey Sound. It adheres to the
under-sides of granite boulders. It is troublesome to keep in
captivity, as it must be lifted daily out of the water for a couple of
hours to supply the place of the fall of the tide. It is necessary to
chip off the piece of stone to which the base adheres, for if removed
from its attachment it seems to have no power of adhering to any
new locality. We have never observed a specimen which had
been detached from its foothold re-attach itself, though it might
live for some time at the bottom of the tank.

As this animal has been rarely met with, and never fully
described, we append a full account of its external form.

Form.—Urn-shaped when expanded; quarter of an inch in
diameter, rather more in height; globular and furrowed when
contracted. In the extended state the animal has a conspicuous
flexible *stalk*, with an irregularly expanded, flat, adhesive foot:
the stalk forms about half the entire height, and when the animal is
contracted assumes an anular appearance. The *umbrella* is broadly
campanulate, its distal end being reflexed or turned out, and
furnished with numerous over-arching tentacles. The *sub-umbrella*
is deeply concave; half-way between its tentacular edge and the
mouth (measuring along an imaginary line drawn from the
tentacles to the lip of the mouth) four buttress-like processes
issue from the sub-umbrella and stretch across to the mouth, each
joining the latter at one of its four corners. Between these
buttresses the sub-umbrella forms deep pouches, each pouch being
bounded externally, and to a certain extent inferiorly, by the

sub-umbrella, internally by one of the sides of the quadri-
lateral columnar mouth-tube, and laterally on each side by one
of the buttresses. The *mouth* is very variable : it is at one
moment a plain four-sided funnel ; at another it is closed and
folds its thick lips so that the oral aperture becomes a mere slit,
or perhaps four slits, arranged like a St. Andrew's Cross. In
large specimens the limbs of this cross may be still further
modified by zig-zag foldings. The *tentacles* are knobbed and
numerous : in normal specimens we have never found less than
thirty-six, and never more than ninety-six. In small specimens
they are set in a single row; in large specimens they are set
in two or more rows, and are divided into eight groups. We
believe the following is the arrangement that obtains in adult
forms :—eight small tentacles are more remote from the mouth
than the rest ; four of these correspond accurately with the
buttresses and mouth-angles, and divide the tentacular margin
into quarters, the other four mark the centre of these quarters.
Each of these eight principal tentacles has a small tentacle on
either side and a little in front of it. Sometimes these small
tentacles are not knobbed, but rather pointed ; in large specimens,
however, they are knobbed like the rest. Between each pair of
these groups, consisting of the principal and adjacent and small
tentacles, are nine large knobbed tentacles, in each alternate
eighth of the margin four of these being in front and five behind,
five being in front and four behind in the remaining eighths.
There is a slight rim or parapet outside the tentacles; the tenta-
cles do not appear to be retractile, but when the animal closes,
they are turned inwards and downwards, and covered by the rim
being drawn closely over them.

Colour.—Dirty chocolate-brown throughout, the stalk being
paler than the rest, the darkest portion being the masses of
generative organs which appear through the transparent body-
wall. The tentacles have a core of dark colouring both in the
tube and in the knobs. The stalk also has a dark core, while the
expanded foot is transparent.

Some individuals obtained at Dalkey exhibited a bright
brick-red colour shining through their tissues. These individuals
were growing among colonies of *Amœrœcium proliferum* the
colour of which they resembled.

In the allied forms, *Depastrella*, *Tessera*, and *Tesserantha*, Haeckel figures ridges running along the umbrella, and dividing it and the stalk or crest into four regions. No such ridges are to be seen in *Depastrum cyathiforme*. In his description of this animal, Allman states that the stalk is ringed regularly. We have seen rings on the stalk when it is not stretched to its full length, but they are not constant, are sometimes incomplete, and invariably disappear when the animal is erected to its full height.

In adult forms the umbrella usually exhibits a somewhat quadrilocular form, being bulged out by the the large bundles of generative organs which are arranged in four V-shaped dark masses, and may be distinctly seen through the more pellucid body-wall.

In a few specimens we found existing a hexagonal, not an octagonal, arrangement of the parts; one such specimen had 108 tentacles in twelve groups of nine each, approximately equal. The tentacles, when the animal was not quite expanded, appeared not to be arranged in groups, but to form three continous rows. Sections of this specimen showed that it possessed six mesenteries, six gastro-genital pockets, and six radial chambers. We found that the arrangement of mesenteries and chambers in normal specimens, as revealed by sections, agreed with that described by H. James-Clark.

Sections cut across a very young specimen demonstrated the absence of the radial chambers in the earlier stages of growth.

Longitudinal sections show that the animal possesses a circular muscle, ectodermal in origin. The mesogloea is thrown into a number of folds which project out into the ectoderm, and on which the muscles cells are arranged. The muscle is well defined and by no means diffuse. It is situated outside the tentacles, and its presence will account for the appearance of the contracted animal.

As the result of the careful examination of numerous specimens, continued over an extended period of time, we are of opinion that the animals described by Sars, Allman, and Gosse, must all be relegated to one and the same species as that which we have found. We believe that the different points of distinction attributed by Sars to *Lucernaria cyathiformis* (Fauna Litt. Norveg. [1846] p. 26,

pl. 3, figs. 8–11), by Allman to *Carduella cyathiformis* (Quarterly Journal of Microscopical Science [1860], vol. viii., p. 125, pl. 5, figs. 1–6), by Gosse to *Depastrum cyathiforme* (Ann. & Mag. Nat. Hist. [1860] vol. v., p. 481), are due to the variations to be met with in specimens of different ages and sizes, and to the variability of habit exhibited by the animal. This view has already been suggested by H. James-Clark (Journ. Boston Soc. Nat. Hist. [1863] vol. vii., p. 550, *n.*

XVII.

ON A PHOTOGRAPHIC METHOD OF DETECTING THE
EXISTENCE OF VARIABLE STARS. By J. JOLY, M.A.,
Sc.D., F.R.S.

It is very probable that the number of variable stars known to us
is but a small fraction of the actual number of such stars. Many
of such stars doubtless possess so small a degree or so slow a
rate of variation of brightness as to render observation by us of
the changes impossible, at least by any existing method of observa-
tion. But there is probably a large number of stars, whose varia-
tions might be observed if a continuous photometric record of their
brightness could be kept. This method should be such as would
keep under observation, not one, but groups of many stars simul-
taneously, for there is, of course, a large degree of chance that
an observer, systematically observing some few stars at random
might not be so fortunate as to include a variable star among
the number.

Another quality which should be possessed by any photometric
method applied to this study is that of being automatic, meaning
by this that its record should be independent of the physiological
state of the observer's eyesight, and independently of him, con-
tinuously record the intensity of illumination, for the variations
sought for may be very slow. I venture to suggest the following
method of meeting these requirements by the aid of photography.

If the photographic plate, instead of being fixed within the
telescope in the ordinary way, were driven with a slow eccentric
circular motion, so that the image of each star describes a small
circle on the surface of the plate, the intensity of the light from
the star might be observed upon successive favourable nights,
over long periods of time; the strength of the circular curve
traced upon the plate depending upon the brightness of the star
and the rate at which its image travels upon the sensitive film.

The plate, when developed, would thus reveal a number of circles, or part-circles, of stars down to the magnitude at which they failed to impress their paths on the film.

The examination of these traces would reveal, on comparing successive plates, in the case of any appreciable variation in brightness of a particular star, either a strengthening or weakening of the linear image, or possibly a complete fading out of the trace.

Irregularities in the driving gear or atmospheric influences would, in affecting all stars upon the plate in a similar fashion, be probably in this way differentiated from real variations in brightness.

A full exposure of six minutes has been recommended by the Paris congress as suitable for securing good measurable images of eleventh magnitude stars. A linear velocity of one millimetre in from ten to thirty minutes would probably secure sufficient linear definition of stars down to the eleventh magnitude. But of course the most suitable rate to meet any particular requirement would be matter of trial. The radius of the circular motion is also of importance, as the number of complete linear images obtained at any particular exposure would be the more reduced the larger the radius employed, the images moving off or entering upon the plate in its extreme positions. In connexion with this latter consideration, a circular movement commends itself in preference to any other. It would also probably cause a minimum of confusion in the overlapping or crossing of images.

XVIII.

ON THE DISTORTION OF PHOTOGRAPHIC STAR IMAGES DUE TO REFRACTION. By PROFESSOR ARTHUR A. RAMBAUT, M.A., D.Sc.

Amongst the principal advantages of the photographic method of making astronomical measures is the fact that, by its aid, much larger distances can be measured than is possible in the case of direct observations with any other instrument than the heliometer; but when the distances over which the measures extend reach such large proportions as 2000″ or 3000″—distances which are by no means uncommon in the study of astronomical photographs—the various disturbing causes, which affect the relative positions of the stars, become very much more effective than in the case of the shorter distances with which, up till recently, we have been accustomed to deal.

The most important of these disturbing causes is the refraction.

In the "Astronomische Nachrichten," No. 3125, I have recently published formulæ, by which the correction for refraction to the relative position of any two stars on the plate may be computed in a manner which I have found in practice to be exceedingly convenient. Since, however, the stars are constantly changing their distance from the zenith all the time that the exposure of the plate continues, the correction for refraction is also constantly changing, and a certain distortion in the shape of the images must take place, the amount of which will vary according to the altitude of the star and the length of time during which the exposure lasts. This distortion will, no doubt, be a small quantity; but in the more delicate researches of astronomy, such as the determination of the parallax of a fixed star, where we aspire to measure a quantity

of less than one-tenth of a second, every possible disturbing cause must be examined into and allowed for with all available rigour.

In order to investigate how far the image of a star on a photographic plate can be distorted by the refraction, I take the formulæ which I have given in the "Astronomische Nachrichten" for the correction for refraction in R. A. and declination respectively.

If we denote by a and δ the R. A. and declination of any star, and by ϕ the latitude of the observatory, and by θ the sidereal time of the observation; if, further, da and $d\delta$ denote the differences in R. A. and declination between this star and another, and if Δda and $\Delta d\delta$ denote the corrections for refraction to da and $d\delta$ respectively, and β be the coefficient of refraction at the zenith distance of the star, we find,

$$\Delta da \cos \delta = \beta \left\{ \frac{\cos \phi \sin \nu \sin (\mu + \delta)}{\cos \delta \sin^2 n \sin^2 (m + \delta)} \cdot da \cos \delta + \frac{\cot n \cos (m + 2\delta)}{\cos \delta \sin^2 (m + \delta)} d\delta \right\},$$

and

$$\Delta d\delta = \beta \left\{ \frac{\cos \phi \cos \nu}{\cos \delta \sin^2 n \sin^2 (\mu + \delta)} da \cos \delta + \frac{1}{\sin^2 (m + \delta)} d\delta \right\},$$

in which m, n, μ, ν are determined by the equations,

$$\tan m = \cot \phi \cos (\theta - a), \qquad \cot \mu = \tan \phi \cos (\theta - a),$$

$$\cot n = \sin m \tan (\theta - a), \quad \text{and} \quad \cot \nu = \cos \mu \tan (\theta - a).$$

Hence we may write—

$$\Delta da \cos \delta = AX + BY, \text{ and } \Delta d\delta = CX + DY,$$

in which X and Y are the rectangular co-ordinates on the plate of the second star referred to the first as origin, the axis of X being in the direction of the parallel at the first star, and A, B, C, and D are constants computed for the position of the first star at the moment of observation.

This is a form of the expression which is exceedingly convenient where a number of stars on one plate have to be measured.

But it will be seen that θ, the sidereal time, occurs in the quantities A, B, C, D, which consequently are not absolutely constant when the exposure lasts for an appreciable time. In the neighbourhood of the horizon, too, the value of β changes so rapidly that another source of variation is introduced.

In taking astronomical photographs of a group of stars it is usual to select one star as guider, and setting this on the intersection of a pair of cross lines in the focus of the guiding telescope before the plate is exposed, to keep it exactly on this intersection all the time the exposure continues. The driving clock of the telescope, of course, if correctly rated will keep the instrument continually pointing at the star, but it is necessary, in order to correct the minute irregularities which are inseparable from even the best of clocks, and to eliminate the effect of the changes of refraction on the motion of the guiding star, to control the movement with the hand by means of the fine-motion-apparatus provided for that purpose. But even with these precautions, it is still only possible to keep one star fixed in position on the plate. Hence the amount by which the image of another star is disturbed on the plate is measured by the change which takes place in the differential refraction relatively to the first star between the beginning and the end of the exposure.

Hence, if A_0, B_0, C_0, D_0 are the values corresponding to the beginning of an exposure, and A_1, B_1, C_1, D_1 those calculated for the end of it, we shall find the amount of distortion—

in RA $\qquad = (A_1 - A_0)\ X + (B_1 - B_0)\ Y = aX + bY,$

and in declination $= (C_1 - C_0)\ X + (D_1 - D_0)\ Y = cX + dY.$

From these equations I have computed the following tables which give the values of the quantities a, b, c, d, for $0°$, $20°$, $40°$, and $60°$ of declination, and for every fifteenth degree of hour angle, the quantities A_0, B_0, C_0, D_0 being taken as referring to the time of the meridian passage of the star, and ϕ being taken as the latitude of Dunsink Observatory, viz. $53°\ 23'\ 13''$.

Table I.—Declination 0°.

Hour Angle.	a	b	c	d	Zen. Dist.
1 h	0·00002	0·00011	0·00011	0·00003	54°48′
2	·00009	·00025	·00025	·00016	58 54
3	·00027	·00052	·00052	·00049	65 13
4	·00079	·00125	·00125	·00143	72 39
5	·00322	·00468	·00468	·00596	81 7

Table II.—Declination 20°.

Hour Angle.	a	b	c	d	Zen. Dist.
1 h	0·00001	0·00007	0·00006	0·00001	35°21′
2	·00003	·00014	·00012	·00003	40 32
3	·00009	·00023	·00022	·00011	47 55
4	·00019	·00037	·00040	·00026	56 18
5	·00041	·00061	·00077	·00064	65 12
6	·00104	·00115	·00180	·00187	74 4
7	·00403	·00684	·00672	·00872	82 34

Table III.—Declination 40°.

Hour Angle.	a	b	c	d	Zen. Dist.
1 h	+ 0·00001	0·00005	0·00005	0·00001	16°52′
2	·00002	·00012	·00011	·00002	24 21
3	·00003	·00019	·00017	·00004	32 57
4	·00006	·00029	·00027	·00008	41 54
5	·00010	·00042	·00042	·00017	50 39
6	·00015	·00064	·00065	·00038	58 56
7	·00020	·00099	·00104	·00086	66 34
8	·00028	·00161	·00175	·00206	73 18
9	+ 0·00027	·00269	·00301	·00531	78 58
10	− 0·00010	·00419	·00479	·01369	83 3

TABLE IV.—DECLINATION 60°.

Hour Angle.	a	b	c	d	Zen. Dist.
1 h	− 0·00001	0·00004	0·00007	0·00000	10°33′
2	·00001	·00008	·00015	·00000	17 34
3	·00002	·00014	·00023	·00000	25 3
4	·00004	·00022	·00032	·00001	32 24
5	·00007	·00033	·00043	·00002	39 27
6	·00014	·00048	·00055	·00009	45 58
7	·00024	·00065	·00067	·00021	51 51
8	·00039	·00081	·00077	·00040	56 54
9	·00061	·00090	·00079	·00069	61 2
10	·00086	·00082	·00069	·00103	64 6
11	·00107	·00050	·00041	·00133	65 59
12	·00116	·00000	·00000	·00145	66 39

The accompanying curves (figs. 1, 2, 3, 4) are traced with these quantities as ordinates, the hour angles being taken as abscissæ, and the "Zenith Distance Curve" is added in each case for convenience of reference. In the case of the B and D curves the ordinates have been measured below the line of abscissæ to avoid confusion. From these curves, or from the tables themselves, it is easy to find the amount of the distortion which a star image undergoes when the exposure lasts from any given hour angle to any other. For instance, if a star at the equator is photographed from the time when its hour angle is 4^h to the time when its hour angle is 5^h, we find, in Table I.,

	(a)	(b)	(c)	(d)
Corresponding to 4^h,	0·00079	0·00125	0·00125	0·00143
,, ,, 5^h,	·00322	·00468	·00468	·00596
Difference,	0·00243	0·00343	0·00343	0·00453

Now if we consider another star on the plate which differs in *R. A.* and declination from the guiding star by 1000″, or, which

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.
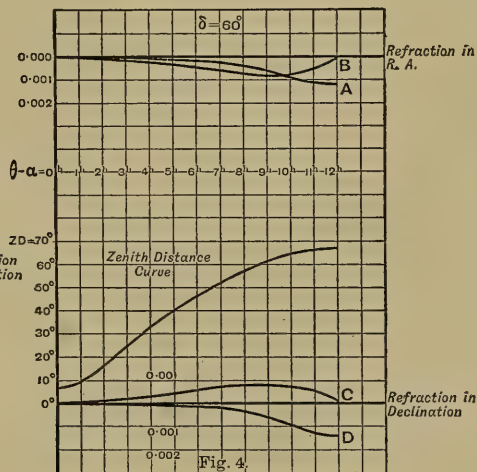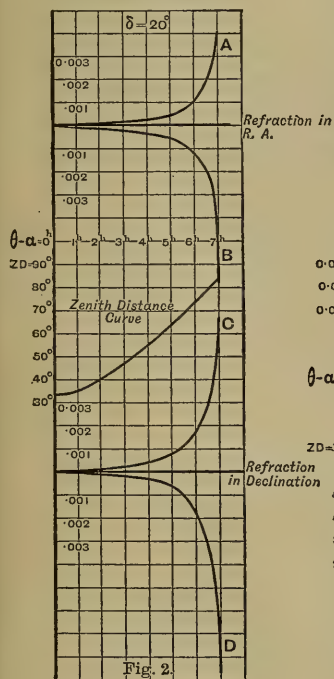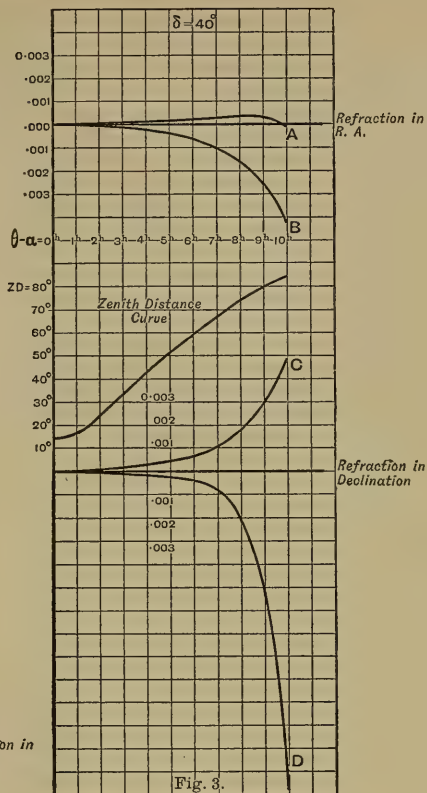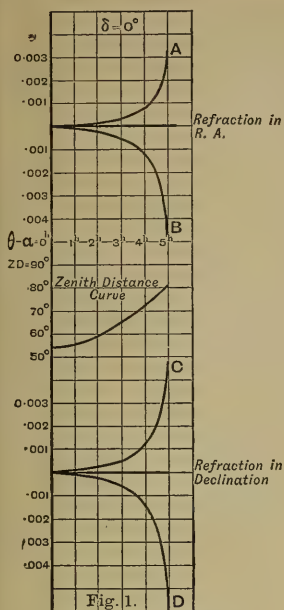
is the same thing, a star at a distance of 1414″ and position angle 45°, we find the distortion—

in *RA*

$= 0.00243 \times 1000″ + 0.00343 \times 1000″ = 2″.43 + 3″.43 = 5″.86,$

and in declination

$= 0.00343 \times 1000″ + 0.00453 \times 1000″ = 3.43 + 4.53 = 7.96.$

Hence we see that the centre of the image of the second star will be drawn out through a length of nearly 10″, and will make an angle of about 36° with the direction of the parallel in which the diurnal motion takes place.

This is, of course, rather an extreme case, as it will be seen from the "Zenith Distance Curve" that, while the hour angle changes from 4^h to 5^h, the star passes from a zenith distance of 73° to about 81°, a position in which no very great precision could be expected.

If, however, we refer to the curve corresponding to 40° declination (fig. 3), and investigate the distortion which the star undergoes in passing from 60° to 75° zenith distance, we shall find the following quantities. Corresponding to a zenith distance of 60° we find the hour angle $6^h.12$, and to 75° an hour angle $8^h.25$, and for these hour angles we find,

	(a)	(b)	(c)	(d)
at $6^h.12$	0.00014	0.00067	0.00070	0.00040
at 8 .25	.00028	.00183	.00204	.00270
	0.00014	0.00116	0.00134	0.00230

If therefore as before we take da and $d\delta$ each equal to 1000″ we shall find,

$$aX = 0″.14, \qquad cX = 1″.34,$$
$$bY = 1.16, \qquad dY = 2.30,$$
$$\therefore aX + bY = 1.30, \qquad cX + dY = 3.64.$$

Hence the distortion amounts to 3″.87 in a direction inclined to the parallel by an angle of about 17°.

It should, however, be remarked that in this case the exposure would last for more than two hours which is a much longer

exposure than would in any case be given to a plate intended for accurate measurement, in which case the exposure will generally be limited to fifteen minutes at most.

Of course if the change in the refraction were uniform and the intensity of the light of the star constant, then in all positions, although the star image would no longer be a circle but a line of some sensible length, still by taking the middle of this short line as the point to measure from, and computing our formulæ for the middle of the exposure, we should eliminate the effect of refraction. But in the neighbourhood of the horizon the rate at which the refraction changes is very rapidly accelerated, and the intensity of the light of the star rapidly diminished by atmospheric absorption as the zenith distance increases. From both of these causes, therefore, the denser part of the star image will lie nearer the position which the star occupied at the beginning of the exposure if the star is approaching the western horizon and the measures made from it will be in consequence affected with error. If the star is near its rising, the end of the exposure will have the greatest effect in determining the position of the image.

It is therefore of importance to investigate how far we may assume the variation of the refraction to be uniform for a quarter of an hour. It will be obvious at once, without calculation, from an examination of the curves in figs. 1, 2, 3, and 4, that down to a zenith distance of 60° we introduce no sensible error by assuming the increase of the differential refraction to be uniform for this limit; and if we compute the amount of distortion in a quarter of an hour from this cause, we shall find that in this time a star · for which da and $d\delta$ are each 1000″ changes its position on the plate,

at a declination of 0° by 0″·15

,,   ,,   ,,   20   ,,   0 ·20

,,   ,,   ,,   40   ,,   0 ·19

,,   ,,   ,,   60   ,,   0 ·09

In a quarter of an hour, too, the star's zenith distance will not vary by more than 3°, by which it will not lose one-hundredth part of its light, so that we need not consider the minute change in its photographic activity.

We thus conclude that, within the limits we have taken, so long as the zenith distance does not exceed 60°, no sensible error can arise through the distortion of a star by refraction if the measures are in all cases made from the centre of the image, and the coefficients in the formulæ of reduction are computed for the time corresponding to the middle of the exposure; but that if photographs obtained with longer exposures are utilized for the determination of the relative position of stars, it will be necessary to know what star on the plate was used as guider, and the distortion by refraction must be investigated for all stars at any considerable distance from it.

XIX.

ON SOME PYCNOGONIDA FROM THE IRISH COASTS. By
GEORGE H. CARPENTER, B. Sc., Lond., Assistant
Naturalist in the Science and Art Museum, Dublin.

(PLATE XII.)

THROUGH the kindness of my friend Professor Haddon I have
recently had the opportunity of examining the Pycnogonida,
dredged in 1890-91 by the "Fingal" and "Harlequin," when
engaged in surveying the West Coast fisheries under the auspices
of the Royal Dublin Society. At his suggestion I now sub-
mit a report on this material; and, through the courtesy of my
chiefs, Drs. Ball and Scharff, I am enabled to add what may be
learned from the specimens preserved in the Dublin Museum of
Science and Art. Altogether I have examined eight species of
these animals from our coasts, five of which are not in the list
given by Thompson (1), which is, so far as I know, the only
memoir on Irish Pycnogonida ever published. That list contains
nine species,[1] and I regret that I can only confirm three or four
of them. Inquiry from Mr. S. B. Stewart, Curator of the Belfast
Museum (to whom my best acknowledgments are due), has elicited
the reply that Thompson's specimens are not in that institution,
and it is to be feared that they have not been preserved at all. Their
discovery, if possible, is specially desirable, as half the species are
referred to forms described by Goodsir, as to the identity of whose
species the greatest doubt exists among recent workers at the
group. Also, the great majority of these specimens were obtained
from the north of Ireland, while the specimens which I have
examined are all from Dublin Bay or from the west. The present
list must therefore be regarded as representing but a small part of
what we may hope to learn of the Irish Pycnogonida, when all
our coasts have been adequately searched.

---

[1] *Munna Kroyeri*, Goods., which is not a pycnogon at all, but an isopod, appears in
Thompson's list by some strange error.

Family.—**NYMPHONIDÆ**.

Genus.—Nymphon, Fab.

Nymphon gracile, Leach (Johnst.).

This species has been found in Dublin Bay by Mr. W. F. de V. Kane, and in Queenstown Harbour by Professor Haddon. It is also recorded from the shores of Antrim and Down by Thompson. As it is described and figured very clearly by Johnston (3), there can be little doubt that Thompson's determination may be accepted, and that this form may be presumed to have a wide range around our coasts. Beyond the British Isles it is known from the south coast of Norway and the shores of Denmark and Holland; and Schimkéwitsch (2) has recently recorded it from the coast of South America, off Cape Vergini, where a single specimen was found by the " Vettor Pisani." It frequents shallow water.

Nymphon rubrum, Hodge.

At present, this species is known in Irish waters, only from Dublin Bay and Dalkey Sound, where Professor Haddon dredged several individuals of both sexes in 1882. A single female was also secured off Dalkey Island, in September, 1892, by the Dublin Naturalists' Field Club. Except in the British seas, it has only been found on the southern coast of Norway (7).

Nymphon gallicum, Hoek.

This fine species, which was described by Hoek (4), from the coast of Brittany, is not recorded for any other locality than the west coast of Ireland. An adult male taken by Miss A. Warren, in April, 1892, on the shores of Killala Bay, was noted by me in the *Irish Naturalist* (vol. i., p. 168). The species has also been found at Broadstone by Mr. A. G. More, and at Broadhaven by Professor Haddon. It was dredged by the " Fingal " in Brandon Bay (St. 18), at a depth of from 9–16 fms. on a sandy bottom, and by the " Harlequin " (St. 160) in Boffin Harbour, at a depth of 1 or 2 fms., among sand and weeds. Quite recently I have received specimens from Mr. A. R. C. Newburgh, from the shores of Bantry Bay, taken at low-water mark. This, like *N. gracile*, appears to be a shallow-water species.

Thompson's list contains four other species of *Nymphon*. " *N. grossipes*, Linn." is inserted on the authority of Templeton's old list (5) as occurring in the north of Ireland, but what species is meant by this it is quite impossible to say. *N. Johnstoni*, Goods. (6) is recorded from Belfast Bay. This is one of the old species which modern writers have failed to recognise. From an examination of Goodsir's figures, I am inclined to regard it as identical with *N. grossipes*, Fab. (Kr.), which, together with the allied species is clearly defined and excellently figured in Sars' recent work (7). It is to be hoped that future investigations of our northern coasts may reveal which of the larger Nymphons are really to be found there. Another species from Donaghadee (10 fms.) is called *N. femoratum*, Leach, by Thompson, but the identity of this will probably always remain uncertain, as swollen thighs (Leach's specific character) are characteristic of nearly all female pycnogons. The fourth species has been recognised by Sars, and I therefore insert it in the present list; it is placed, together with some other northern Nymphonidæ, in a special genus.

Genus.—CHÆTONYMPHON, Sars.

Chætonymphon spinosum (Goods.).

Nymphon spinosum, Goods.

Thompson records this species from Belfast Bay. Goodsir (6) gave no locality for his type, but probably took it in the North Sea. Sars has found it off the west coast of Norway (7). It ranges farther south than any other species of its genus, which is characteristic of Arctic seas.

Family.—PALLENIDÆ.

Genus.—ANOPLODACTYLUS, Wils.

Anoplodactylus petiolatus (Kr.).

This minute but very distinct species is represented by a single female example dredged by the " Harlequin " (St. 223) in Loughrosmore Bay, Co. Donegal, from a sandy bottom, at a depth of 4–9 fms. It was first described from the Danish seas. Under the name of *Pallene pygmæa*, Hodge (8), it is described from Plymouth Sound and the coast of Durham, while

as *Phoxichilidium pygmæum*, Hoek (4) records it as occurring off the coasts of Brittany and Holland at a depth of 1–7 metres. Dohrn (9) found it also in the Mediterranean, and described it as *Pallene longicolle;* and Sars records it from the south and west coasts of Norway. Lastly, Schimkéwitsch (2) obtained a single example from the "Pisani" collections, taken at Port Lagunas, in South America. The species has therefore an extremely wide range.

Genus.—Phoxichilidium, M.-Edw.

Phoxichilidium femoratum (Rathke).

This species occurs both on the east and west coasts. Miss A. Warren has found it in Killala Bay; Mr. Kane has obtained it in Dublin Bay, and Prof. Haddon in Dalkey Sound. Thompson records it (as *Orythia coccinea*, Johnst.) from Strangford Lough. This is a widely-distributed northern species, recorded from the coasts of Greenland, Lapland, Norway, Denmark, and Scotland. The species from the eastern coast of North America, *P. maxillare*, Stimps., is in all probability identical; but I would follow Sars in regarding Hoek's *P. femoratum* (4), from the coasts of Brittany and Holland, as distinct from the present form.

Thompson records also *Phoxichilidium globosum*, Goods. (6), from Portmarnock. This is a species which it is hardly possible to recognise without types. It can scarcely be identical with *P. femoratum* (as Sars thinks possible), for Goodsir was apparently acquainted with that species, and gives points of distinction between them. Possibly it is identical with Hoek's *P. femoratum*.

Family.—**PHOXICHILIIDÆ.**

Genus.—Phoxichilus, Latr.

This genus is sometimes classed in the same family as *Pycnogonum*. The two genera agree in having both lost their three foremost pairs of appendages, except the false legs of the males. But they differ so considerably in other points, as to suggest that they have reached their present degraded state through quite independent lines of descent. Schimkéwitsch (10) suggests that *Phoxichilus* has come down from the Nymphonidæ through the Pallenidæ, while *Pycnogonum* has been derived from a form resembling *Rhynchothorax*, as Dohrn (9) also believed.

Two distinguishable forms of *Phoxichilus* occur in our seas, yet so nearly related that it is doubtful whether they should be regarded as distinct species. They have, however, been differentiated and named by former observers; so I venture to keep them separate, at least until intermediate forms are found connecting them.

Phoxichilus spinosus, Mont.

[Pl. XII., figs. 1, 3, 5, 7.]

P. spinosus, Hoek (in part).

A single male of what I believe to be the typical form (11) of Montagu's species, was dredged by the "Fingal" off Aran Island in July, 1890. In his remarks on the *Phoxichili* from the coast of Brittany, Hoek (4) mentions that two males, out of ten referred by him to *P. spinosus*, were much larger and more spiny than the others. He found no corresponding females, and was hence led to infer "un dimorphisme dans le sexe masculin." Through the kindness of my friend, Prof. D'Arcy Thompson, of Dundee (who has in many ways helped me in the study of this group), I have been able to examine a male and female from Plymouth (where Montagu's type was taken), and females from Jersey, which correspond closely with the Aran specimen; the females are, however, less spiny than their mates. They differ from the next form (*P. lævis*) in being nearly twice as large,[1] having the proboscis much thicker proportionally at the end, bearing conspicuous spines on their lateral processes, and showing more numerous and larger spines on the legs. The openings of the cement-glands on the femora of the male number twenty-five or twenty-six (fig. 5): nearly the same number (twenty-four) as Dohrn (9) gives for his large Mediterranean species, *P. charybdæus*. Our form agrees with *P. charybdæus* in its swollen proboscis; but the latter species has the spines on its lateral processes less conspicuous or absent. It has, moreover, relatively longer legs than *P. spinosus*. Two conspicuous blunt spines are present (fig. 1) at the front of the cephalic segment in the male; in the female they are hardly to be recognized.

---

[1] 6 mm. long and 40 mm. in extent. Montagu gave one-fourth of an inch as the length of his type.

Phoxichilus lævis, Grube.

[Pl. xii., *figs.* 2, 4, 6, 8.]

P. spinosus, Sars (7), Schimk. (10) ; *P. spinosus*, Hoek (4) (in part).

This form is, as has been said, much smaller[1] and less spiny than the true *P. spinosus*. The structural differences, pointed out above, are, however, so relative that many naturalists would hesitate to rank the two forms as " species." There are only nineteen or twenty cement-gland openings on each femur of the male in this form (fig. 6). The spines on the lateral processes are small or absent. There is no doubt from Sars' figures and descriptions (7) that this is the *Phoxichilus* which occurs on the west coast of Norway. Grube's types (12) were from the Breton shore, where Hoek also found the animal, and referred it, as mentioned above, to *P. spinosus*.[2] Jarzynsky is said to have taken it also on the coast of Lapland. On our coasts, Dr. Scharff found specimens cast up on the North Bull, Dublin Bay, after a strong S.E. gale in October, 1892. Miss A. Warren sent it to me last summer from Killala Bay,[3] and Mr. A. R. C. Newburgh has found numerous examples in Dunbeacon harbour at the head of Dunmanus Bay. Many of the males in this consignment bore egg-masses.

I have figured parts of these two Phoxichili for comparison (Pl. xii.), the corresponding organs in each being drawn to the same scale.

The proboscis of this form is not swollen at the end (fig. 2) as much as that of *P. spinosus* (fig. 1) ; but both forms have the proboscis thicker in the male than in the female. In the shape of the proboscis, *P. lævis* closely resembles *P. vulgaris*, Dohrn, from the Mediterranean; the latter is, however, a smaller and more slender animal, and the male has but fifteen or sixteen cement-glands on each femur. Schimkéwitsch (10) has recently given detailed descriptions of the species of *Phoxichilus*, and notes various points of difference between the present animal and *P. vulgaris*. He seems, however, to have had but very few specimens of each

---

[1] 3–4 mm. long and 25 mm. in span.

[2] In his Report on the " Challenger " Pycnogonida, however, Hoek says that *P. lævis* may be readily distinguished from *P. spinosus*.

[3] I recorded these in the *Irish Naturalist*, vol. i., pp. 42, 165, as *P. spinosus*.

for comparison, a serious drawback in such a variable genus, in examples of which too much stress must not be laid upon the presence or absence of individual spines. For example, as a rule, we find but three spines at the end of the dorsal aspect of the femur in *P. lævis* (fig. 6), while *P. spinosus* has five (fig. 5); but in some examples which I would refer to *P. lævis*, the two supplementary spines are present, though very small. Grube's distinction by the absence of the two frontal spines is not reliable. They are generally absent, but not always, and are figured as present by Sars. The shape of the proboscis, and the number of cement-gland openings on the male femora seem the only constant distinctions, not only between *P. spinosus* and *P. lævis*, but also between these and Dohrn's two Mediterranean species.

It seems to me that *P. lævis* has as much right to distinction from *P. spinosus*, as from *P. vulgaris*, or as *P. charybdæus* has from *P. spinosus*. The four forms are, however, so very similar in most structural points, that whether they are to rank as " species " or " varieties " must remain a matter of opinion. It seems not unprofitable to note their minuter details, for it is at least possible that the naturalists of the future may be able to observe the further divergence of these forms until they become undoubtedly distinct species.

The genus appears, as has been said, to have arisen from Nymphon-like ancestors, and to be one of the most recently differentiated genera of the group. With this suggestion its distribution agrees, for while its head-quarters are the North Atlantic and the Mediterranean, we know that it is represented at scattered points in the southern hemisphere. Böhm (13) described a species *P. meridionalis* from Singapore; Haswell (14) records *P. charybdæus* from the coast of Australia, and Schimkéwitsch found a female of the same species in the " Pisani " collections from the Abrochos Islands off the coast of Brazil (2). This distribution contrasts with that of an older genus, such as *Nymphon*, which ranges uniformly over the temperate and cold seas of both hemispheres; it also contrasts with the truly discontinuous distribution which would characterise a still more ancient genus which was on the way to extinction. We may infer, therefore, both from the difficulty of marking off the species of *Phoxichilus* and from its

range in space, that it is a genus of comparatively recent origin which will, in course of time, develop into several well-marked species.

Family.—**AMMOTHEIDÆ**.

Genus.—Pasithoe, Goods.

Pasithoe vesiculosa, Goods.

Thompson records a single specimen from off Dalkey Island, which he referred to this species. The genus is one which can hardly be recognised by modern authors; yet, as the form cannot be proved identical with any previously described pycnogon, I think it best to insert it, and trust that the types may be recovered, or fresh specimens secured, which will place its identity beyond doubt. From a consideration of Goodsir's figures (15, 16), I would regard *Pasithoe* as nearly allied to *Ammothea*, and not to *Collosendeis* with which Sars (7) associates it.

Family.—**PYCNOGONIDÆ**.

Genus.—Pycnogonum, Brünn.

Pycnogonum littorale, Str.

This is our commonest species of pycnogon, and there can be little doubt that it occurs all round the coast. It is recorded by Thompson from Bangor, Co. Down, and from Dublin Bay, under the name of *P. balænarum*, this name having been erroneously given to the animal through its confusion with the amphipod *Cyamus*, which is parasitic on whales. *P. littorale* has been taken at the North Bull, Dublin, and also in Dalkey Sound, by Prof. Haddon. It was dredged at several stations off the west coast, in great numbers, by the "Fingal":—Clew Bay, 15 fms.; Galway Bay (St. 21), 16 fms., sand; off Achill Head (St. 64 and 72), 144 fms., and 127 fms. fine sand; off the Skelligs (St. 114), 80 fms., sand and mud. Beyond the British seas, this species is known from off the coasts of Lapland, the White Sea, Iceland, Greenland, Denmark, Germany, Holland, Belgium, France, North America, Japan, Chili, and Kerguelen. Its bathymetric range is as remarkable as its geographical extension. On our own coasts it has now been traced from the shore to a depth of nearly 150 fms.;

and Wilson (17, 18) notes specimens from the east coast of North America from more than three times that depth.

The specimens which I have examined, obtained in March and April, are all immature, while those taken in June, July, and August, are nearly all adult. The egg-mass carried by the male is circular, like a cushion, and nearly as large as the animal itself.

My best thanks are due to Prof. Haddon and to the collectors mentioned above, who have kindly supplied me with the specimens; and I am specially indebted for the generous help afforded me by Prof. D'Arcy Thompson in giving and lending me specimens for comparison. This paper must be regarded as but a preliminary record on the subject; and it is to be hoped that systematic work, specially around our northern coasts, may largely increase the knowledge of Irish Pycnogonida.

REFERENCES.

(1) THOMPSON, W. :
   "The Natural History of Ireland," vol. iv. London, 1856, (p. 412).

(2) SCHIMKÉWITSCH, W. :
   "Sur les Pantopodes recueillis par M. le lieutenant G. Chierchia pendant le Voyage de la corvette 'Vettor Pisani' en 1882–1885."—*Atti della R. Accad. dei Lincei* (4) Memorie vi., 1890, p. 329.

(3) JOHNSTON, G. :
   "An Attempt to ascertain the British Pycnogonidæ."—*Mag. Zool. Bot.* i., 1837, p. 368.

(4) HOEK, P. P. C. :
   "Nouvelles Études sur les Pycnogonides."—*Arch. Zool. Exp. et Gén.*, ix., 1881, p. 445.

(5) TEMPLETON, R. :
   "Catalogue of Irish Crustacea, Myriapoda, and Arachnoida."—*Mag. Nat. Hist.*, ix., 1836, p. 9.

(6) GOODSIR, H. D. S. :
   "Descriptions of some new species of Pycnogonidæ."—*Edinb. New Phil. Journal*, xxxii., 1842, p. 136.

(7) SARS, G. O.:
   "The Norwegian North Atlantic Expedition, 1876–78." Vol. xx.,
      "Zoology—Pycnogonidea," Christiania, 1891.

(8) HODGE, G.:
   "List of the British Pycnogonoidea, with Descriptions of several
      new Species."—*Ann. Mag. Nat. Hist.*, (3) xiii., 1864,
      p. 113.

(9) DOHRN, A.:
   "Fauna und Flora des Golfes von Neapel, III. Pantopoda."—
      Leipzig, 1881.

(10) SCHIMKÉWITSCH, W.:
   "Notes sur les Genres des Pantopodes."—*Arch. Zool. Exp. et
      Gén.* (2) ix., 1891, p. 503.

(11) MONTAGU, G.:
   "Description of several Marine Animals found on the south
      coast of Devonshire."—*Trans. Linn. Soc.*, ix., 1818, p. 81.

(12) GRUBE, E.:
   "Mittheilungen über St. Malo und Roscoff, ..."—*Abhandl.
      der Schlesischen Gessellsch. für vaterl. Cultur*, 1869–72, p. 75.

(13) BÖHM:
   "Pycnogoniden des Museums zu Berlin."—*Monatsber. der K.
      Acad. der Wissens. zu Berlin*, 1879, p. 189.

(14) HASWELL, W. A.:
   "On the Pycnogonida of the Australian coast."—*Proc. Linn.
      Soc. N. S. W.*, ix., 1885, p. 1025.

(15) GOODSIR, H. D. S.:
   "On a new genus of Pycnogonidæ."—*Edinb. New Phil. Journ.*,
      xxxiii., 1842, p. 367.

(16) ———
   "On the specific and generic characters of the Araneiform
      Crustacea."—*Ann. Mag. Nat. Hist.*, xiv., 1844, p. 1.

(17) WILSON, E. B.:
   "Report on the Pycnogonida of New England and Adjacent
      Waters."—*U. S. Comm. of Fish and Fisheries Report for
      1878*, Washington, 1880.

(18) ———
   "Report on the Pycnogonida" in the "Reports on the Results
      of the dredging along the east coasts of the United States
      . . . by the . . . 'Blake,'" 1880.—*Bull. Comp. Zool. Harv.*
      viii., 1881, p. 239.

EXPLANATION OF PLATE XII.

Figure 1.—Front of cephalic segment, and proboscis of *Phoxichilus spinosus*, Mont. (male).

,, 2.—Front of cephalic segment, and proboscis of *P. lævis*, Grube (male).

,, 3.—False leg of *P. spinosus* (male).

,, 4.—False leg of *P. lævis* (male).

,, 5.—Femur of 4th pair of *P. spinosus* (male), *c. g.* openings of cement-glands.

,, 6.—Femur of 4th pair of *P. lævis* (male), *c. g.* openings of cement-glands.

,, 7.—Tarsus and propodus of *P. spinosus* (female).

,, 8.—Tarsus and propodus of *P. lævis* (female).

Figs. 5, 6, 7 and 8 are all drawn to the same scale; figs. 3, 4 to a somewhat smaller scale; and figs. 1 and 2 to a still smaller scale.

XX.

ON A GRAPHITIC SCHIST FROM CO. DONEGAL. By RICHARD J. MOSS, F.C.S., F.I.C.

GRAPHITE is recorded as occurring at a number of places in Ireland. Mr. G. H. Kinahan, in his Paper on Irish Metal Mining,[1] mentions localities of the mineral in the counties Clare, Donegal, Kilkenny, Mayo, Tipperary, Wexford, and Wicklow. I have been unable to find a published analysis of the graphite from any of these localities; accordingly, I take the opportunity of placing on record the chemical composition of a graphitic mineral which has recently come under my notice. The specimen is from Glendown, in the parish of Gartan, Letterkenny, Co. Donegal, a locality in which the occurrence of graphite has not previously been recorded. The rock was found in large quantity by a Mining Company in sinking a shaft in the metamorphic schists. The specific gravity of the rock is 2·662, and it yielded the following results on analysis :—

H_2O, expelled at 100° C.,	0·98
,, ,, a red heat,	3·68
Carbon,	3·15
Sulphur,	4·03
Ash, allowing for the displacement of sulphur by oxygen,	87·89
	99·73

I found the ash to consist of—

SiO_2,	58·91
Al_2O_3,	19·87
Fe_2O_3,	7·40
CaO,	4·86
MgO,	1·63
Na_2O,	3·54
K_2O,	3·73
	99·94

With traces of Mn and Ni.

---

[1] Scientific Proceedings, Royal Dublin Society, N.S., vol. v., p. 250.

Plate IX.

Irish Polychæta.
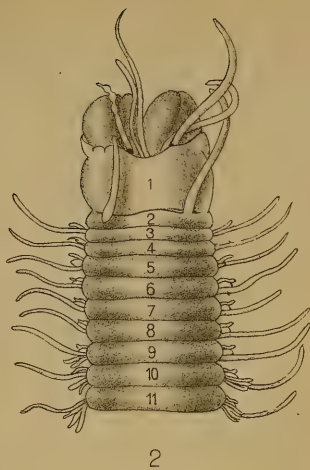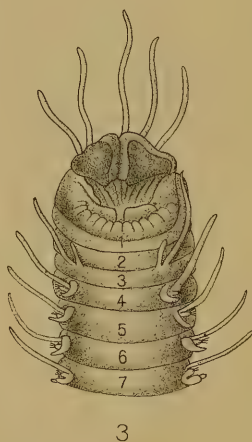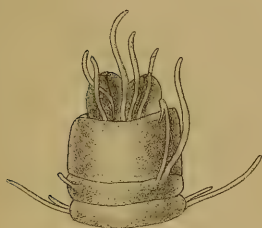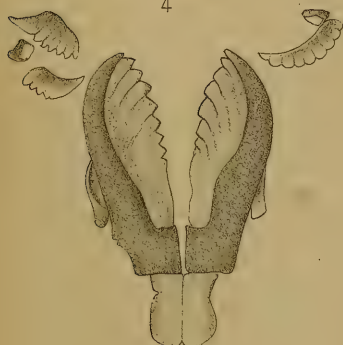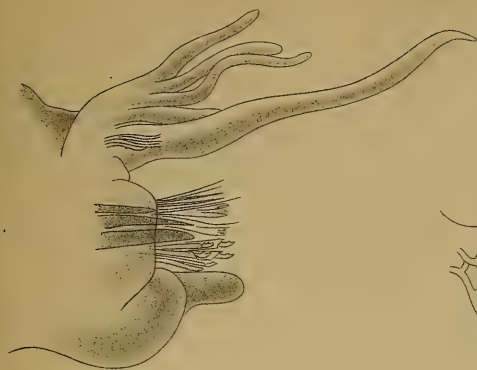
7b

7a

7c

8

9

10

12a.

12b

12c

11

Irish Polychæta.

Plate XI.

Irish Polychæta.

Plate XII.

THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

CONTENTS.

The Authors alone are responsible for all Opinions expressed in their Communications.

Royal Dublin Society.

FOUNDED, A.D. 1731.   INCORPORATED, 1749.

EVENING SCIENTIFIC MEETINGS.

THE Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and ready for transmission to the Editor.

From the external characters of the rock it would not be supposed that it contains little more than 3 per cent. of carbon. It has the lustre of graphite, though of a grayish tint, and possesses the foliated structure so frequent in that mineral. It soils the fingers like graphite, but marks paper badly. Comparing the composition of the ash with that of the ash of graphite, the quantity of alkali present in this rock is large. In the case of fifteen analyses of graphite, quoted by Dana and Brush in their "System of Mineralogy," the largest quantity of alkali in the ash is 2·2 per cent., whereas in this graphitic rock there is 7·27 per cent. of the oxides of potassium and sodium.

XXI.

NOTE ON THE PRESENT CONDITION OF THE WATER IN
THE RESERVOIR AT ROUNDWOOD. By W. E. ADENEY,
F.I.C., F.C.S., Curator in the Royal University of Ireland.

ON Saturday, November the 11th, I paid a visit to the Vartry
Waterworks at Roundwood, in company with my friend Mr.
Moss, we both wishing to see the condition of the Reservoir after
the prolonged season of drought through which we in Dublin and
its neighbourhood have been passing. It is not, however, my
object in this note to describe the condition of the Reservoir, but
to record one or two interesting results which I have obtained
from a careful chemical examination of samples of water therefrom,
which I collected at points just before and after it had passed
through the filter-beds.

The condition of the unfiltered water in the Reservoir was, at
the time of our visit, of particular interest, because the question
naturally suggested itself, had the water suffered in quality in
consequence of the prolonged drought? It was only to be
expected that the water in the Reservoir would indicate, on
analysis, more than ordinary contamination with organic matters;
for the water therein must have undergone considerable concentra-
tion during the past seven months of dry weather; furthermore,
the contents of the Reservoir had been appreciably augmented
by somewhat heavy rains two or three days previously, which, in
all probability, had washed more than ordinary quantities of dead
vegetable matters into the Reservoir, considering the dryness of
the collecting area and the advanced season of the year.

The sample of unfiltered water which I brought away with me
contained a good deal of yellow clay and some peaty matters in
suspension; it was very decidedly turbid, and of a greenish-brown
colour. The sample of filtered water was, on the other hand,
quite free from suspended matter; it was clear and bright, and
tinged very faintly with a greenish-brown colour.

In the following table are given two series of analyses of each sample; one series of each sample being made on the Monday (November 13th), following the Saturday on which they were collected, and the other series on the second Monday (November 20th) following. The samples employed for the two second series of analyses were kept, during the week's interval, out of contact with the air in glass-stoppered bottles. I ought also to state that the original samples, from the time they were collected at the Waterworks until the commencement of the analyses, were kept in bottles completely filled and carefully stoppered with glass stoppers.

TABLE GIVING THE RESULTS OF ANALYSES.

[*Results expressed in parts per* 100,000.]

In fresh Samples.

Constituents.	Unfiltered.	Filtered.	Differences.
Nitrogen as albuminoid ammonia, .	0·009	0·005	—
Nitrogen as ammonia, ...	0·032	0·001	+ 0·031
Nitrogen as nitrates, ...	0·033	0·069	− 0·036
Nitrogen as nitrites, ...	0·000	0·000	—
Total combined inorganic nitrogen, .	0·065	0·070	− 0·005
Chlorine, ...	1·100	1·100	—
Dissolved gases :—			
Carbon dioxide, ...	1·250	1·386	− 0·136
Oxygen, ...	1·143	0·935	+ 0·208
Nitrogen, ...	2·092	2·124	—

In Samples kept out of contact with air for seven days.

Constituents.	Unfiltered.	Filtered.	Differences.
Nitrogen as albuminoid ammonia, .	—	—	—
Nitrogen as ammonia, ...	0·030	0·001	+ 0·029
Nitrogen as nitrates, ...	0·035	0·069	− 0·034
Nitrogen as nitrites, ...	0·000	0·000	—
Total combined inorganic nitrogen, .	0·065	0·070	− 0·005
Chlorine, ...	—	—	—
Dissolved gases :—			
Carbon dioxide, ...	1·257	1·403	− 0·146
Oxygen, ...	1·146	0·931	+ 0·215
Nitrogen, ...	2·085	2·125	—

Confining our attention for the present to the results of the analyses of the fresh samples, one of the first points which will strike us is the decided quantity of free ammonia present in the unfiltered water, and the interesting fact that practically the whole of it becomes nitrified to nitric acid during the passage of the water through the filter-beds. This nitrification we may take in the light of recent research to be the result of the activities of the gelatinous layer of living matter gradually deposited on the surfaces of the material composing the upper portions of the filter-bed.

Other evidence of the activity of the nitrifying organisms in the filter-bed, besides the oxidation of ammonia here shown, is afforded by the decrease in the quantity of dissolved atmospheric oxygen, and in the increase of the carbon dioxide, which the water suffers on passing through the filter-beds. The figures in the table giving the weights of these gases in the unfiltered and filtered waters respectively, show that a decrease of oxygen equal to ·208 and an increase of carbon dioxide equal to ·136 really occur during the passage of the water through the filter-beds. On calculation, the quantity of oxygen required to oxidize the quantity of ammonia which is nitrified during filtration, viz. ·031 parts, will be found to be equal to ·117, while the weight of oxygen combined with ·136 parts of carbon dioxide will be found equal to ·099. The two quantities of oxygen, ·117 and ·099, together equal ·216. This is somewhat in excess of the loss shown by the analyses, viz. ·208, and allows nothing for other possible oxidations or absorption by the organism. I have invariably found, from a large number of experiments I have made on nitrification, that a loss of oxygen occurs over and above that required for the nitric acid and carbon dioxide which had been formed. The probable explanation of this not appearing in the analyses under discussion is, that it was quite possible for the water at the point where the sample was collected to have undergone slight oxygenation from the air after it had passed through the filter-beds.

A further point of interest in these analyses is the insight they give into the character of the organic matters, both in the unfiltered and filtered waters. So far as the albuminoid-ammonia test can indicate, the quantity of organic matter in the filtered

water is well under the limit usually allowed to a good potable water; that, however, in the unfiltered water, just exceeds it. A careful examination, however, of the analytical data given in the above table will, I think, lead to the conclusion that the organic matters in both unfiltered and filtered water may be classed as unfermentable, and may, in consequence, be regarded, both from experience and our present knowledge, as presenting no danger to health.

Let us consider, in the first instance, the filtered water. The fact that the very decided quantity of free ammonia in the unfiltered water became practically completely oxidized to nitric acid during the passage of the water through the filter-beds proves that the water had undergone a very strong process of oxidation, one, in fact, which warrants the conclusion that all fermentable organic matters, if any were present in the unfiltered water, must have been completely oxidized. This conclusion is warranted by the results of all bacteriologists and chemists who, so far as I am aware, have made the products of destructive metabolism of saprophytic organisms a special study. Their results all tend to show that, with all fermentable organic matters, when dissolved or mixed with water, and exposed to the influence of saprophytic organisms, the organic carbon becomes first oxidized, chiefly to carbon dioxide, the oxidation of the carbon in nitrogenous matters being usually attended with the formation of ammonia and other substances. From a large number of experiments I have made on this subject, I have found that the ammonia so formed, or purposely added, only begins, under ordinary circumstances, to suffer oxidation after most of the organic carbon has been oxidized, and then, and not till then, does the ammonia begin to become oxidized. When nitrification has set in, then the amount of ammoniacal nitrogen oxidized may much exceed in proportion the amount of organic carbon simultaneously oxidized to carbon dioxide.

The question then arises, what is the character of the organic matters left in the water after they had passed such a strong process of oxidation as that we have seen to be exerted by the organism in the surfaces of the material composing the filter-bed? There can be no doubt that the remaining organic matters were either derived from peat, or are similar in character to the colouring matters found in peat.

I trust in a further communication to be in a position to give good reasons for regarding the colouring matters of peat, as secretions by saprophytic organisms when thriving on dead vegetable matters. Some two years ago I read a short note before the British Association Meeting at Cardiff, on the olive green, and brown colouring matters, which are secreted by saprophytic organisms, when grown under certain conditions in fresh town sewage. I found, under the conditions referred to, the fermentable organic carbon in fresh sewage was oxidized to carbon dioxide, and that ammonia was at the same time formed, which in its turn was oxidized to nitrous and nitric acids. The final products were liquids, coloured brown and greenish-brown, which underwent no further fermentation. The green and brown colouring matters were indistinguishable from similar coloured matters from peaty streams.

If this explanation of the origin of the organic matters in the Vartry water be the correct one, we can understand at once the reason for their appearance in the filtered water from the works at Roundwood; and we can regard the chemist's opinion that peaty matters, when present in small quantities in potable waters, present no danger to health, a safe and proper one.

We have next to consider the character of the organic matters in the unfiltered water. I have already pointed out that they exceed slightly the limit usually allowed to good potable waters, so far as the albuminoid test can indicate. The point of importance is, is any of the organic matter in the water fermentable? We have a proof that fermentation must have occurred in the water at some time of its previous history, in the presence of the decided quantities of free ammonia it contained. It was accordingly a matter of great interest to ascertain whether (1) there were still present in the water any fermentable organic matter, and (2) whether any nitrification was going on in the water itself.

To put these points to the test, a sample of the water was kept completely out of contact with air for seven days, and again analysed. A sample of the filtered water was also similarly kept and analysed. The two analyses are given in the above table. A glance at the results will show no change occurred to the dissolved gases, or free ammonia, in either unfiltered or filtered water on keeping for seven days, the slightest variation in the

figures being due to the experimental errors. We may draw from these results the conclusions that neither the unfiltered nor filtered water contained an appreciable quantity of fermentable organic matter. We may also draw the interesting conclusion that no nitrification took place to any appreciable extent during the space of seven days in the unfiltered water. I have no doubt that nitrifying germs did exist in the sample of unfiltered water experimented with. The explanation of the negative results of the experiment rather lies in the probable inactivity of the germs than in their total absence. These germs must have opportunity of developing and multiplying very rapidly before they will set up nitrification to any appreciable extent. This statement is borne out by one which the Royal Commission upon the Metropolitan Water Supply make in their Report recently published in reference to the action of a filter-bed. The Commissioners state:—"The action of a filter-bed appears to be partly mechanical, partly vital; but the mechanical action which is confined, or almost confined, to the holding back of the grosser substances suspended in the water, which was supposed until recently to be the only operation in a filter, is now held to be of far less importance than the vital action which depends on the activities of the gelatinous layer of living matter gradually deposited on its surface. A new filter, composed of perfectly purified sand, has little or no effect in producing either chemical or bacteriological purification; but, in course of use, a layer charged with living microbes is deposited upon the surface, and it is by these organisms which constantly increase in number, and also penetrate the sand to a slight distance, that both the nitrification of organic matter and the arrest of other microbes is effected."

Referring again to the experiment of keeping the samples of unfiltered water out of contact with air, I should like to add that I believe, from other experiments I have made, that a negative result in the search for nitrification would not have been obtained in the case had I been able to keep the sample for a longer period. In time I have no doubt that the ammonia would have been completely nitrified, the organism deriving the carbon for their metabolism from the colouring matters in the water; but this is a question requiring further experiment, and which I must leave for a further communication.

Some reference to the decidedly large quantity of nitrates, shown by the above analyses to be present in the filtered water, is necessary. I have not had occasion to analyse before the Vartry water immediately it leaves the filter-beds, and therefore cannot of my own experience say whether the quantity given in the above table is to be regarded as normal or not; it is certainly much higher than we are accustomed to find in the same water as delivered in Dublin. I do not remember for instance to have ever found a larger quantity than that represented by ·01 parts of nitrogen per 100,000 in water drawn from the main which supplies the Royal University, and I have from time to time examined many samples of the water supplied to the Laboratory of that University.

XXII.

USEFUL METHODS IN TEACHING ELEMENTARY PHYSICS.
By J. JOLY, Sc.D., F.R.S.

I.—*The Barometer—Boyle's Law—Air Thermometer—Cooling of a
gas upon expansion—Flotation of Bodies.*

THE subject of elementary scientific education is of so much
importance that I do not think it out of place to bring before
the Society methods I have found of use in teaching elementary
experimental physics.

The Barometer.—It is a good plan to ask a student who seems
in a difficulty, what it is that he does *not* understand, and keep a
careful note of such answers, for it is beyond the power of most
teachers to recall their own difficulties when *they* were beginning.
Beginners commonly find difficulty in understanding how the pres-
sure of the atmosphere upon the surface of the mercury in the
bath supports the column of mercury in the barometer. It is a very
justifiable difficulty, in a sense, and it is best to put it that the
bath is not essential at all, save to keep air from going up the tube
and to supply mercury ; and to show the student what happens
when the tube is slowly lifted till it leaves the bath. The next step
is to convince him that the atmospheric pressure had really been
supporting the mercury all along. In this it is only requisite to
take a barometer tube of sufficiently fine bore (about 2 mm.) and
pour in some 72 cm. of mercury. Invert it, and the mercury
hangs up in the tube. Why ? Then add a little more mercury,
and when the then prevailing barometric length is reached, the
column begins to sink down in the tube. Just when it is going
to fall out, dip it into the bath. Now the column is secure, and
it is plain to the pupil that dipping it in the bath cannot alter
the atmospheric pressure which supports it, but the pressure must
now be transmitted through the mercury in the bath.

This experiment may be shown to a whole class by the follow-
ing arrangement :—A tube of thin glass about 1 cm. bore and

90 cm. in length, as uniform in bore as possible, is fitted with a floating piston, as described by me upon a former occasion.[1] Here I will describe a form specially suited to the present purposes (see accompanying figure). *a, b, c, d* is a cylindrical ivory box turned very flat and sharp-edged on the face *a, b*. It fits the glass tube so truly that it just sinks slowly in it when the tube contains air. The end *c, d* screws off. *f* is a solid cylinder of ivory turned with a neck *g*, by which it is attached to the box. The float is shown as it acts at the base of a column of mercury; it keeps the base from breaking, although the column be violently jogged up and down in the tube. Nor can air pass from below the mercury piston to above it except the tube be considerably inclined. It will be understood now that the box form is conferred upon *a, b, c, d* so that little weights (fine wire) may be put into it to counteract the flotation-pull of *f* if this is too strong. Of course this may also be accomplished by taking something off the bulk of *f* till the flotation force is adjusted.

With this float we may suspend a column of mercury in the wide tube up to the barometric length, and a whole class may see it, the ivory piston being very conspicuous.

I may add here that it seems very important not to speak of the vacuum as " sucking up " the mercury. It is my experience, in fact, that it is most important to impress upon the student the absolute *inertness* of the vacuum. In the vacuum there is nothing worth speaking of, and how can " nothing " pull up the mercury? The mercury is *shoved up*, not pulled up. Similarly this is of importance in explaining the operation of lifting water by pulling up the piston of a pump. The water is being pushed up after the piston by a force equal to that which supported the hanging column of mercury; in fact, this push is helping us to lift the atmosphere pressing on the piston. When the shoving force is used

---

up, the water will not help any further or rise any further, and we may pull up the piston as high and dry as we please, supporting then the full atmospheric pressure upon the piston unaided.

Boyle's Law.—Take the glass tube, as previously described; drop in the piston, with the float f upwards, towards the open end. Let it sink till about half way down; then pour down a little mercury, and raise the tube upright. A certain volume of air is enclosed below the piston and mercury. Fix the tube by a clip on a retort-stand. Hold up a scale beside it, and read the length V_1 of the column of air, also the length m_1 of the mercury. Write these down. Add to m_1—with an obvious explanation— the length of a column of mercury equal to the barometric length (or the length of the just-sinking hanging column), and write up the added lengths as P_1, under the number V_1. Multiply these together.

Now pour mercury down the tube till m_1 has increased to 50 or 60 cm. Measure this length. Add, as before, the barometric length, writing this up as P_2. Then read V_2 by the scale, and multiply V_2 by P_2, and show that $P_2 \times V_2$ is (closely) equal to $P_1 \times V_1$.

In carrying out this experiment, it is necessary to guard against handling the lower part of the tube, or temperature errors will arise. It is also requisite to leave the volume V_2 a few moments to assume the temperature of the air and part with the heat generated in it by compression. Very accurate measurements may be made if the lower end is cooled in melting ice during experiment, and more advanced students might be asked to plot successive volumes and pressures. Such might be required also to determine accurately the successive volumes by weighing the tube afterwards when containing mercury—in fact, to calibrate the tube.

To prove Boyle's Law for pressures lower than the atmospheric pressure it is only necessary to imprison the air above the mercury, the closed end of the tube being then uppermost. In this case some mercury is first poured into the tube, and the floating piston then dropped in. Inverting the tube slowly, some air is let pass up above the mercury. The length of mercury in the tube is deducted from the height of the barometer for P_1. To alter this pressure a stick or glass rod is passed up the tube

from below, and pressing this against the base of the piston, as much mercury as it may be desired to remove is caused to fall down past the float. The mercury remaining, the float now rises into a new position in the tube. P_2 and V_2 may then be read.

The advantage which this tube possesses over Boyle's is, I think, evident. The complication of the rise of mercury in the upturned end of the latter being avoided, and, indeed, the operations are evident at a glance.

The Air Thermometer.—Drop the piston down the tube—as before, with float uppermost—and seal with mercury when about two-thirds down. Then place vertically with the lower 30 cm. in ice, supporting the tube by a loosely closed clip fixed to a retort-stand. When a few minutes in the ice add mercury till the air is compressed to the volume 273 millimetres. It is best to adjust a little indiarubber band, at this level, previously. Now lift up the tube and remove the ice, substituting a flask with hot water, carried upon a flat pattern Bunsen burner, and having a neck so long that it rises some 40 cm. upon the tube. Bring the water up to boiling, and placing a little cotton-wool in the mouth of the flask, to secure that the tube is for 40 cm. immersed in steam. The piston and mercury rapidly rise during this operation. A second rubber ring upon the tube is now slipped down to mark the stationary position finally attained by the lower surface of mercury. If the tube is now lifted from the flask and the length up to the ring measured, it will be seen to be 373 millimetres. Therefore we have shown that

$$\frac{V_0}{V_{100}} = \frac{273}{373}.$$

In fact, there has been an expansion of $\frac{1}{273}$rd of the volume at 0° for each degree rise of temperature. Hence, if we had been able to cool the gas 273° below 0°, the gas would have zero-volume (theoretically). Therefore 273° C. is temperature of theoretical zero-volume. We then draw a figure of the tube, numbering it on one side—273° C., 0° C., 100° C., 200° C., etc., from below upwards. On the other side, at same points, we write consecutively 0, 273, 373, 473, etc., and explain that this last scale has the obvious advantage of expressing at once the volume of the thermometric substance, *e.g.* the gas. So that when a change of temperature

occurs from T_1 to T_2, a given mass of gas will change in volume from V_1 to V_2, so that

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}.$$

We also explain that we may express T as $273 \mp t°$, where $t°$ is temperature read on an ordinary centigrade thermometer. With these data we now can combine the law of Boyle with the law of the expansion of a gas, in the usual manner, arriving at the result

$$\frac{V_1\, P_1}{273 + t_1°} = \frac{V_2\, P_2}{273 + t_2°}.$$

Cooling of a gas upon expansion. Presence of moisture in the atmosphere. Snow on high mountains.—A striking experiment, teaching a great deal, is the following :—A strong copper vessel (preferably spherical, about 6 cm. diameter) is fitted with a screw valve and attachment, so that it can be connected with a bottle of liquid carbon dioxide, and some of the liquid transferred to it. This transference is facilitated by cooling the copper vessel with a little ether when the connexion is made.

The copper vessel, clean and bright upon the outside, is hung by a wire from a retort-stand ring, and the valve screwed open before the class. In a few moments a thick covering of white frost overlays the bright copper, and continues to grow into a thick shell of ice. Finally this melts and drops off the sphere as water. Let the student, by tasting, see that this is *water*, and not something derived from the escaping gas. The experiment may be repeated, placing the vessel in a small beaker containing a little phosphorus pentoxide or calcium chloride, and letting the gas escape while the beaker is closed by a cardboard cover. No ice, or very little, now collects. But without the repetition of the experiment it is quite apparent that :—

1. The gas leaving the sphere has permitted the residual gas to expand, and this has produced a very marked cooling of the vessel.

2. The air must contain a great deal of moisture to account for all the ice upon the vessel.

3. The air gives up its moisture when cooled.

In drawing conclusions from those facts, it is well to show the students photographs of the Alps (if not already familiar with the appearance of high mountains), and the phenomena observed in the experiment impressed upon them as a principal cause of the cold on high mountains. They should also, of course, be reminded of the moisture upon the carafe of iced water, &c. Young students should be made to write down upon dictation pithy statements in their note-books as to the leading facts observed and the deductions drawn, for such are not able to report the words of a speaker.

It will be seen that the experiment displays all the phenomena involved in the dynamical explanation of cold on high mountains, save the motion of the winds.

Flotation of bodies, Archimedes' principle.—Plane down a piece of light pine till it is of a uniform cross-section, a square of 1 cm. on the edge. Let it be about 30 cm. in length. Drill a hole in one end, and load with lead till it floats upright in water. About two-thirds will be immersed. Divide it into centimetres and half-centimetres from the loaded end, and varnish it.

The student weighs this on a balance, and then places it in water. If it weigh 20·5 grammes, it sinks 20·5 cms. in the water. He places a single gramme weight on the upper end : it sinks to 21·5 cms. He then measures it carefully, and convinces himself that each centimetre immersed must displace 1 cub. cm. of water. But as he has already learned that a cub. cm. of water weighs 1 gramme, evidently the weight of the water displaced is equal to the weight of the floating body, or a floating body displaces its own weight of water.

By making this float hollow, closed with a cork at each end (cardboard, varnished, does very well), its use may conveniently be extended to proving Archimedes' principle. In this case, weights may be dropped down the floating tube, removing the cork, and will not tend to overturn it.

Let the student put in weights till anything more will sink it. At that moment it displaces n c.cs., and when he weighs it he finds it weighs n grammes. Now it is easy to see that the body will not displace any more water when wholly submerged, but the weighing has proved that the ultimate displacement produced an upwards-directed force equal to the weight of the displaced water.

The submerged tube must be pressed up still by this force, *i.e.* by a force equal to the weight of water displaced, Q.E.D.

Observations upon floats of various cross-sections furnish useful and well-recognized exercises for the student.

NOTE ADDED IN THE PRESS.

In measuring volumes in the form of Boyle's tube described above, it conduces to accuracy to leave a little mercury standing in the lower end of the tube, and thus avoid the necessity of making assumptions as to the volume of the hemispherical extremity of the tube. The tube is thus virtually converted into a flat-ended tube.

XXIII.

ON THE INFLUENCES OF TEMPERATURE UPON THE
SENSITIVENESS OF THE PHOTOGRAPHIC DRY
PLATE. By J. JOLY, D.Sc., F.R.S.

The fact that a photographic plate loses in sensitiveness at low
temperatures has already been the subject of experiment. But I
am not aware of any experiments beyond those of Abney and
Dewar, which were, so far as I can learn, confined to exhibiting
the broad fact of the loss of sensibility. Many practical photo-
graphers have also, I believe, been aware of the fact from every-day
observation.

Some couple of months ago, being then in ignorance of previous
observations on the subject, I made experiments upon an Edwards'
isochromatic plate and upon a Wratten fast plate. The sensitive
plate was backed, one-half with a poultice of solid carbonic acid,
just made into a paste with ether; the other half with a poultice
of hot water in flannel. It was, in this state of unequal heating,
exposed behind a double layer of thick plate-glass to a gas flame.
Upon development, the cold half showed but little light-action;
the hot was strongly affected. The double window of plate-
glass is essential to keep moisture from depositing and obscuring
the cold half. A thin piece of glass is cooled so quickly that it
obscures before there is time to expose it. The naked plate
rapidly becomes frosted on the cold half.

In this experiment I observed that the effect was more
marked upon the isochromatic than upon the plain silver bromide
plate. It appeared of interest to find if this loss of sensitiveness
could be traced to a loss of activity of the Eosin sensitizer to
rays of low refrangibility, thus accounting for the more marked
effect upon the isochromatic plate.

To investigate this point, I modified a quarter-plate printing
frame, so that a plate might be divided into a hot and cold area

longitudinally by poultices, as before described. Upon this the spectrum was formed, from an electric arc, of such dimensions as nearly to extend the full width and length of the plate.

When an isochromatic plate (Edwards') was exposed for a few seconds to the spectrum and developed, it was found that the warm half of the plate showed the usual appearance: strong over the violet and blue, with a weak region in the blue-green (between F and E), and again a vigorous action in the green and yellow-green (between E and D), fading off gradually to the orange-red. This green-yellow sensitiveness is well known to be especially the result of the action of the dye.

On the cold half of the plate, over the violet and blue regions, there was an equal, or very nearly equal, density to that obtaining on the warm half; but all beyond, beginning at the weak region, E–F, and extending to the limit of sensibility, there was a most marked and striking loss of sensibility. Over the weak region there had been no action, or very little; the dense band marking the green-yellow was weakened and narrowed, showing, however, no shifting, and the yellow and orange again were almost without density.

Some ordinary gelatino-bromide plates (Wratten's and Cadett's) were next tried. In the case of these the hot and cold regions did not exhibit so marked a difference. The warm extended, indeed, further beyond F towards E, and there was a slightly inferior density all over the cold spectrum. I am not perfectly sure if this last is a real effect, for some stray light and fogging introduce uncertainty as to whether this may not be—in some degree at least —due to the inferior sensibility between E and F. For such rays in the stray light would be inactive over the cold, and active over the warm halves of the plate. The most marked effect is, however, in this case also towards the less refrangible rays.

It remains to consider how these results may be interpreted in connexion with theories of photo-chemical action and the action of the special sensitizers.

In the first place, we might consider that the deprivation of heat simply affected the fundamental silver bromide molecule, rendering it less resonant to the long wave-lengths, and hence affecting the photo-reduction on the plain gelatino-bromide plate in so far as this is ordinarily sensitive to long wave-lengths, and

affecting the dyed plate the more seriously, as this is prepared to use the long wave-lengths through the intervention or aid of the dye stuff. The experiments, in fact, revealed that, save for the survival of some activity along the special dense band on the green, the ortho-plate was virtually reduced by cold to the limits of sensitiveness of the undyed plate.

While I am inclined to think that the silver bromide molecule is in some degree affected as above, I do not think the experiments on the gelatino-bromide plate prove that it alone is affected in the orthochromatic plate. On the view (favoured by Abney) that the sensitizing action of the dye is a chemical one, started into operation by a photo-chemical change in the dye, it appears to me very probable that the experiments are, in fact, only one more example of the already long series of chemical actions known to be dependent upon temperature for their activity. Possibly, too, the initial photo-chemical action upon the dye is reduced in intensity at low temperatures. In short, the events set in operation by the light waves are complex, and all concerned with molecular stability, whether towards the periodic forces of light or their mutual attractions. It is most probable that molecular stability towards either action is dependent on the quantity of energy possessed by the molecular system.

In the experiments described above, care must be taken that the plates have arrived at uniform temperature before development, or quite other effects would arise. With my own arrangements I am, of course, unable to estimate the temperature of the film. It is certainly not nearly so low as that reached by the mixed carbon dioxide and ether ($-81°$). With special arrangements, probably, even more marked results could be obtained. Photographs of yellow flowers upon cooled isochromatic plates contrasted with photographs taken on plates at air temperature would show the effects of cold, no doubt, strikingly. In very cold climates isochromatic plates will possess but little advantage over ordinary plates, except they be maintained at a sufficiently high temperature when being exposed. However, the influence of length of exposure has still to be investigated. It might be that long exposure through a medium opaque to the blue and violet light would restore the ' iso '-chromatic quality.

XXIV.

NOTES ON THE VARTRY WATER IN NOVEMBER, 1893.
By RICHARD J. MOSS, F.C.S., F.I.C.

Early in the month of November, 1893, the Vartry reservoir at Roundwood had become almost empty owing to the long continued dry weather. It was found necessary to cut off the Vartry supply from a large area, and to substitute water from another source, but part of the city and some of the townships remained dependent upon the residue of the Vartry water, and it became a matter of importance to ascertain whether this water continued sufficiently pure for drinking purposes. I accordingly commenced a series of daily analyses on November 7th. I had no intention of publishing my results, but as I find there is no public record of the condition of the Dublin water supply of this exceptional period, the following notes, incomplete as they are, may be of interest :—

The samples were taken from the main at Ballybrack, about ten miles from Dublin, from November 7th to the 18th inclusive. I believe the water in the reservoir reached its lowest level on the 16th. The water was darker in colour than it had formerly been, and all the samples were more or less turbid. The greatest turbidity was observed on the 18th.

My examination was confined to determinations which could be rapidly made with small samples of the water. Ammonia and 'albuminoid ammonia' were determined by Franklin's method. The solids were dried at the boiling point of water until loss of weight ceased. The oxygen absorbed was determined by submitting a given volume of the water to the action of an excess of potassium permanganate for four hours at a temperature of 26° C., and titrating with sodium thiosulphate, the results being controlled in each case by an observation upon pure water under identical conditions. Nitrites were absent in each case. Nitrates were not determined on the days on which the samples were drawn; subsequent determinations showed quantities of nitric acid varying from 0·18 to 0·24 grain per gallon.

The results are given in the following Table in grains per gallon :—

Date—November,	7	8	9	10	11	12	13	14	15	16	17	18
Ammonia,	0.0020	0.0008	2.0014	0.0008	0.0007	0.0010	0.0018	0.0018	0.0008	0.0003	0.0022	0.0018
Albuminoid Ammonia,	0.0045	0.0063	0.0045	0.0055	0.0072	0.0054	0.0042	0.0067	0.0063	0.0055	0.0075	0.0049
Chlorine,	0.94	0.92	0.92	0.91	0.92	—	0.92	0.92	0.94	0.94	—	—
Solids,	3.78	4.62	4.20	3.64	4.20	4.48	3.08	3.08	3.78	3.36	3.64	4.06
Oxygen absorbed,	0.053	0.069	0.088	0.094	0.089	0.094	0.078	0.072	0.079	0.086	0.089	0.096

The chlorine was very constant, but the other constituents, and the oxygen absorbed, showed wide variations from day to day.

It will be noticed that an increase in the solids was usually, though not always, accompanied by an increase in ammonia. The largest quantities of 'albuminoid ammonia' occur at intervals of three days; with one exception, these maximum quantities show a progressive increase.

It is generally considered that pure upland surface-water should not absorb more than 0·07 grains of oxygen per gallon. My results show that, on every day after November 8th, that quantity was exceeded. The limit commonly assigned to 'albuminoid ammonia' in really good drinking water is 0·0056 grains per gallon; that limit was exceeded on the 8th, 11th, 14th, and 17th.

There are no means of ascertaining the source of the impurity which these figures reveal, or the cause of the daily variations. The unfiltered water from the Dargle river which was admitted to the mains during this period may have contributed to produce some of the results observed. It is possible, too, that, under the severe strain to which the filter-beds at Roundwood were submitted, filtration was not always efficient. Another possible explanation is to be found in the intermittent character of the supply. That the contents of the mains are affected by the daily turning off of the water is proved by the superaerated condition of the water during this period. When quickly drawn from the service-pipe the water was generally found to present a milky appearance, owing to the abundant separation of gas in minute bubbles. I

found it easy to collect this gas in quantity. The gas escaped from the water issuing from the tap in the proportion of 1 volume of gas to 77 volumes of water at a temperature of 4° C. The composition of the gas, collected on two occasions at an interval of three days, was found to be as follows :—

	A.	B.
Nitrogen, . . .	82·86	84·30
Oxygen, . . .	16·97	15·53
Carbon dioxide, . .	00·17	00·17
	100·00	100·00

A given volume of the gas, exploded with detonating gas, underwent no alteration in volume, and no carbon dioxide was produced; marsh gas and other hydrocarbons were therefore absent. The gas is, in fact, atmospheric air deprived of some of its oxygen, and with an increased quantity of carbon dioxide. Owing to the coefficient of absorption of oxygen by water being greater than that of nitrogen, such a mixture of oxygen and nitrogen would result from the action of water upon air. There can be no doubt as to the source of this air. Assuming the water, when it enters the mains from the reservoir, to be saturated with air, it would, at the same temperature, absorb still more air at the lower level at which it was drawn from the mains, owing to the greater atmospheric pressure at this level. But, instead of being capable of absorbing more air, the water is found to be supersaturated; it must accordingly have been aerated after it left the reservoir. The obvious explanation is that it is aerated in the mains, the air being drawn into the mains by the suction resulting from the outflow of water from the mains when the supply from the reservoir is cut off each day. It is a question for consideration whether the excess of dissolved oxygen does not largely promote the oxidation of the iron mains and the lead service-pipes and cisterns; this, however, is a matter of minor importance. The serious consideration is that the air sucked into the mains is certain in many cases to be derived from tainted sources; and it is highly probable that the defective fittings which admit the air admit liquid impurities also. This result of an intermittent water supply might be attended with disastrous consequences.

XXV.

ON THE LIMITS OF VISION: WITH SPECIAL REFERENCE TO THE VISION OF INSECTS. By G. JOHNSTONE STONEY, M.A., D.Sc., F.R.S., Vice-President, Royal Dublin Society.

CONTENTS.

INTRODUCTORY REMARKS.

THE President of the British Association, at the recent meeting of that body in Nottingham, mentioned in his opening address that the image formed by the compound eye of an insect had been photographed. This suggests the inquiry how the image is formed, and what is the limit of the vision of which it is the physical basis. The investigation of this point shows that insects cannot see very minute objects, and the whole inquiry seemed of sufficient interest to be laid before the Royal Dublin Society, especially as it suggests much further study which the author could not attempt, but which there are other members of the Society most competent to undertake.

SECTION I.—Of Vision in general.

As preliminary to the inquiry it is well to consider what are the causes that limit the amount of detail that can be seen by the instrumentality of eyes such as our own, the kind of eyes of which we know most. That there is such a limit to human vision may be easily seen by placing a well-illuminated ruling of parallel lines at different distances from the eye of a person whose vision is good. Let us suppose black lines ruled, as in figure 1, on a white surface at intervals of one milli-
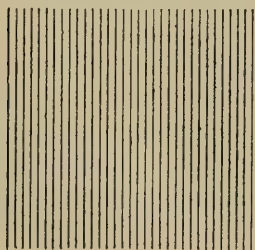
FIG. 1.—MILLIMETRIC RULING.

metre from the middle of one line to the middle of the next. If

an observer with keen vision views these from a distance of eleven or twelve feet, he is able barely to make out that they are a ruling; beyond that distance, they seem one uniform grey surface, while from stations nearer to them he perceives the individual lines distinctly. Now, at a distance of eleven feet a millimetre subtends an angle of 1′ (one minute). Hence we learn from observation that in order that two objects may be seen as two, they must, at least, subtend an angle of about 1′ at the eye. If they subtend a less angle than this they are seen as one object.

Now there are three distinct causes, any one of which is by itself competent to put a limit of this kind to our power of distinguishing minute objects; and in persons with the best vision each of these three seems to put nearly the same limit as the other two. This adjustment between them is, no doubt, the result of development, since any further improvement on the lines of any one of these causes would be useless, unless it were accompanied by a simultaneous improvement in both the others.

One cause is the spacing of the cones that occupy the *fovea lutea*, into the small area of which about 7000 of them are packed. The *fovea lutea* is that spot in the retina which furnishes us with the exceptionally distinct vision which we have in the middle of the field of view. The cones are here without accompanying rods, and are at intervals of about 4μ,[1] measuring from the middle of one to the middle of the next. This interval is about half the diameter of the red corpuscles of human blood, an object familiar to every microscope observer. Again, the "optical centre"[2] of the eye lies a centimetre and a-half in front of this part of the retina;

---

[1] The micron μ is the millionth part of a metre. This is the same as the thousandth of a millimetre, or the 1/25400th of an inch.

[2] From each point of a visible object a cone of rays, starting from that point as its apex, falls on the pupil. In passing through the eye this cone of rays is made to converge, and finally becomes a cone of rays advancing towards that point of the retina where the image is formed. The apex of the second cone is accordingly at this point. Most of the rays of the first cone are bent in passing through the cornea and optic lens, and advance in a new direction in the second cone. But there is one among them, which, in the second cone, continues in the same direction, or at least parallel to the direction which it had in the first cone. This ray is called the undeviated ray. It is easily seen that there is one such ray in the light coming from each point of the object. Now all the undeviated rays very nearly pass through a certain point which is situated close behind the optic lens, and $1\frac{1}{2}$ centimetre in front of the middle of the retina. This is the point which is called the "optical centre" of the eye.

and at this distance the interval between adjoining cones subtends an angle of nearly 1′.   Hence, in order that the images of two points of light may fall on the corresponding parts of different cones, their distance asunder must subtend an angle of, or exceeding, 1′ at the optical centre of the eye; in other words, the interval between the objects in external nature that are being examined, must subtend this angle at the eye.   Thus we fail to see with the unassisted eye much detail which is revealed to us by the microscope.   This happens if at a distance of ten inches, the distance of most distinct vision, the intervals at which these objects are spaced subtend an angle of less than 1′.   Such objects may, however, be seen with optical aid, provided it is such that the little interval subtends an angle exceeding 1′ at the optical centre[1] of the object-lens used in the microscope, a point which, with the higher powers of the instrument, lies close to the object on the stage.   But beyond this limit, and therefore beyond the reach of the microscope, there are still worlds of events in nature which we can never see, although we may infer the existence of some of them in other ways.

We have found that the spacing of the cones in the *fovea lutea* is competent to put a limit to the minuteness of the detail that can be seen with the naked eye.   Now, the small size of the pupil of the eye also, and independently, determines such a limit.   Astronomers are familiar with the fact that the image of a star (which is virtually the image of a point of light, since no telescope is competent to show the true disk of a star) consists of a small round central patch called the spurious disk, surrounded by coloured rings which very rapidly fall off in brightness.   This phenomenon is due to the interference of the light coming from the two halves of the object-lens, and is susceptible of mathematical treatment.   It thus appears that the angular radius of the first dark ring, estimated from the middle of the object-lens, is

$$\theta = (1 \cdot 22)\,\frac{\lambda}{A},$$

where λ is the wave-length of the light, and A the aperture, *i.e.*

---

[1] The optical centre of the object-lens of a microscope is the point where the " undeviated rays " cross (see last footnote).   In compound microscopes this point lies some distance in front of the object-lens, and with high powers is close to the object.

diameter of the object-lens. This furnishes a boundary within which the central spurious disk lies, and up to which its faintest outlying portion barely extends. It also fixes the *minimum visibile* with that aperture, since two points would have begun to be blurred into one another if so close that the middle of the spurious disk of each lay on the first dark ring of the other. Let us then put into this formula, $\theta = 1' = \cdot00029$ in circular measure (this is the limit already fixed by the rods and cones), and $\lambda = \cdot6$ of a micron (which is the wave-length of yellow light). We thus find

$$\cdot00029 = (1\cdot22) \frac{\cdot6}{A},$$

whence $A = 2524$ microns, which is very nearly 1/10th of an inch. This, then, is the diameter of the pupil of the eye when of such size as to put the same limit on the visibility of small objects as the rods and cones do. Now, this is about the size to which the pupil of the eye shrinks when we scrutinize well-illuminated objects, and is the smallest to which it can be allowed to shrink without interfering with the vision of minute detail, by placing a further restriction beyond that imposed by the layer of rods and cones.[1]

Again, the eye viewed as an optical instrument is far from perfect. Its chromatic defect may be detected by placing the finger horizontally in front of the eye, and looking just over it at the bar of a window. In this way the window-bar is viewed through the upper half of the pupil, and is then seen to be bordered with colour. Finally, the spherical aberration[2] of the eyes becomes conspicuous when we view a considerable star or planet with one eye. Instead of being seen as a point, it is seen

---

[1] It might be thought that with the more dilated pupil which we have in faint light, we could see more detail. But the reverse is the case; for instance, the two small double stars ϵ_1 and ϵ_2 Lyræ are more than 3' asunder, and yet, in consequence of their faintness are nearly at the limit of what a very good eye can see distinctly as two objects. To eyes that are fairly good they appear as one object elongated, while persons with only tolerably good sight do not even see the elongation.

[2] If a sphere be drawn round a point of the image formed by light of one wavelength, to represent the crest of one of the luminous waves advancing towards that point, the whole of the crest should reach that sphere at the same instant of time. There are, however, usually little deviations of some parts of the crest of the wave from this sphere, which defect is called spherical aberration.

as a small irregular patch with short tails from it, and of some-
what different shape according as it is viewed with the right or
with the left eye.   Now this is due to spherical aberration co-operat-
ing with another defect which it is difficult to disentangle from
spherical aberration, and which is caused by the light having to
pass through the other layers of the retina before reaching the
rods and cones.   These layers, however, do little harm in the
fovea lutea, as here they are either absent or thin, so that the
irregular image seen when we look *directly* at a planet is chiefly
due to pure spherical aberration.

Now these defects, viz. the chromatic and spherical aberrations,
including under the latter that further defect which arises while
the light is crossing the retina, are dealt with in nature in the
same way in which a photographer deals with them in his photo-
graphic camera, viz. by limiting the aperture, which diminishes
the effect of these imperfections.   We have already found that
the aperture of the pupil is contracted as much as is compatible
with the other conditions to be fulfilled.   Now it is evident that
a certain amount of the defects with which we are at present
dealing, especially when rendered less operative by the limited
aperture of the pupil, may be allowed to remain in the eye without
rendering it incapable of distinguishing objects separated by 1′
of angle, the limit already fixed by the rods and cones; and there
can evidently be no tendency in evolution to effect any further
improvement of the eye as an optical instrument.   Accordingly,
in persons with the best vision, the eye seems to have been just
improved up to this point, leaving its outstanding defects still
very conspicuous when searched for.   And it is shortcoming in
respect to these defects which is chiefly what makes one man's
eyesight less perfect than another's.

We shall next deal with another preliminary remark, which
it is well to make, as it will dispel the oft-repeated error that
there ought to be some connexion between our vision and the
position of the image formed on the retina.   It is pertinent to
point this out when engaged in inquiring into the vision of
insects, for, as we shall see presently, the image formed by com-
pound eyes is erect, while that formed by single eyes, such as
ours, is inverted.   Neither position, however, nor a sideward
position, nor any other, would be incompatible with our seeing

the objects of the world around us exactly as we now do. For the direct physical adjunct of a visual perception in our mind of a point of the object is not any event in the eye or along the optic nerve, but in a more deep-seated part of the brain, probably in its occipital lobes which lie in the back of the head, over the cerebellum. Now [speaking from the physical standpoint] the way in which this event in the occipital lobe is usually evoked is by light from the point of the object being guided through the eye to one of the rods or cones, after which some event travels along one of those nervelets with attendant nerve-cells which penetrate the retinal layer from the expansion of the optic nerve, and each of which is associated with one individual rod or cone. This is succeeded by some event along one fibril of the optic nerve, after which there seem to follow other events within the brain, which finally lead up to *that particular event* which, and which alone, is the true physical adjunct of the visual perception in our mind—our perception of that point of the object from which the light set out to enter the eye. I, for convenience, speak of this event as situated in the occipital lobe, although its location can hardly be said to be ascertained.

Now it is evident that the image on the retina is only one link in this long chain of physical causes and effects, and that the image might be erect as it is in the compound eyes of insects, or inverted as in our eyes, or might have any other orientation, and that nevertheless the positions of the rod or cone, nervelet, fibril of optic nerve, etc., could be so disposed as to produce precisely the same final event within the occipital lobe of the brain as now occurs. Now it is this last alone which is essential, the others being only instrumental in bringing it about: it alone is the true physical adjunct of the visual perception which becomes part of the mind.

Again, although the train of causes and effects described above are the usual process by which this adjunct of perception is evoked, it is not by any means the only way in which it can be brought about, as is conspicuously manifested by dreams, and may be detected by a careful introspective study of the memory of visual perceptions. I am of opinion that in all cases when remembering a past scene there is some dim, usually a very dim, recurrence of the perception, or of parts of it: at all events, under

some circumstances, this is distinctly the case.   When, unfortunately, we lie awake for several hours, especially under the influence of tea or coffee, until a feeling of weariness and an indisposition to any prolonged train of consecutive thought have come over us, I have observed that the revival of visual perceptions, when thinking about past scenes, becomes stronger and is easily perceived, and that in some cases it may become almost vivid.   In extreme cases it even amounts to a kind of dreaming with the eyes open—the dream, however, differing from ordinary dreams by being one the progress of which we can ourselves direct.   It is important to note that these visions are not based on any affection of the retina, and in this respect differ wholly from those spectral images which we see after gazing for some time at objects which somewhat dazzle the sight.   These latter shift their position with every movement of our eye-balls; the others retain what we estimate to be their positions in space, notwithstanding that the eyes be moved about.   Now this is very significant.   It shows that the train of physical causes which lead up to that event in the posterior lobe, which is the adjunct of our perception of these visions, did not originate in the retina, but in a part of the brain where it could arise in conjunction with some of those events which are the physical adjuncts of our judgments about space.   This is an important conclusion to have reached.

What is probably in reality only a further stage of these waking dreams is sometimes experienced in fever, when the patient has been for days without sleep.   I myself saw apparitions in this way, after having been three days without sleep, those I saw having a marvellous appearance of reality, and being seen in the daylight when I could at the same time see in the ordinary way the objects about me in the room, except where one of these novel figures intruded.   In these places the connexion with the retina seems to have been rendered more or less inoperative, and a visual perception, otherwise produced, was substituted for the ordinary one.

Another instructive and more agreeable way of making the observation is to experiment on ourselves when in that stage of drowsiness in which we seem to have gone partially asleep, but not so much so but that we can still voluntarily direct our thoughts to some well-remembered scene, or still better, first to one, and

afterwards to another. If we repeatedly seize opportunities of making this experiment we shall gradually accumulate instances of every degree of vividness, from the full distinctness of a dream in respect of colour, brightness, and form, down to the shadowy dimness of what we very imperfectly see in the exercise of ordinary memory. The same important observation may be made here, as on a former occasion. The objects so seen do not shift their positions when we voluntarily shift our eyes about. They have their origin not in the retina, but in immediate connexion with the part of our brain which is directly related to our judgments about space.

Another interesting observation is of what happens when we get into what is sometimes called a " brown study "—thinking intently upon some past scene that engrosses our thoughts. On such occasions the visual image before " our mind's eye " becomes more vivid than usual, and in the same degree the image produced in the ordinary way of the external objects towards which our eyes may chance at the time to be directed, becomes less distinct, and, in extreme cases, may almost fade out, so that even noteworthy events may happen in our presence which we do not see, or at least which do not impress us sufficiently for us to retain any memory of them.

Two experiences, one of a friend and one of myself, seem worth recording in this connexion :—

Some years ago this friend and I rode—he on a bicycle, I on a tricycle—on an unusually dark night in summer from Glendalough to Rathdrum. It was drizzling rain, we had no lamps, and the road was overshadowed by trees on both sides, between which we could just see the sky-line. I was riding slowly and carefully some ten or twenty yards in advance, guiding myself by the sky-line, when my machine chanced to pass over a bit of tin or something else in the road that made a great crash. Presently my companion came up, calling to me in great concern. He had seen through the gloom my machine upset and me flung from it. The crash had excited the thought of the most likely cause for it, and the event in his brain, which was the physical adjunct of the thoughts thus passing through his mind, were so associated with that other event in the brain, which is the adjunct of visual consciousness, that the one [speaking from the physical standpoint] evoked the other,

perhaps faintly.   This involved a visual perception in the mind, faint, but sufficient on this occasion to be seen with sufficient distinctness when not overpowered by objects seen in the ordinary way through the eyes.

The experience I had myself was one which frequently occurred to me when a lad.   Several of us boys were fond of witnessing sham fights in the Phœnix Park, at which some of the most conspicuous objects were the single horsemen who now and then galloped at full speed, with orders, from one part of the field to another.   Almost always, after a day spent in viewing this spectacle, as I lay in bed at night I saw vividly what seemed to be a tiny horseman galloping violently from right to left, or from left to right as the case might be.   All the movements of the horse were reproduced, the dashing about of the sabre-tasche, the coloured uniform, the movements of the horseman.   It cannot have been in the retina that this revival took place.   It must have been in a much more deep-seated part of the brain.

It would, I think, be of very great interest to ascertain from the inhabitants of a blind asylum, whether those who have recently had their retinas extirpated, or rendered functionless, continue to dream of scenery, so long as the memory of visual perceptions is recent.   I should expect they would, as the structures which they have lost do not seem to be concerned in either memory or dreaming.

From a review of all the evidence it appears clear that the retinal image is only one of the stepping-stones in a rather long progress from the object in nature to the event in the brain, which is the direct adjunct of visual perception.   Why, then, it may be asked, is an image necessary?   Why is it never absent?   Why is not something quite different sometimes substituted for it?   The following is, I think, a sufficient answer.   There must be *some difference* in the events occurring in the occipital lobe in order that two points of an object may be seen distinct from one another.   To bring this about either a different nervelet must have been acted upon in the organ of sight, or the same nervelet must have been differently acted on. In the case that actually occurs, it would appear that a different nervelet is acted upon when the points of the object are sufficiently separated to be seen as two, and that a difference of action on the same nervelet is reserved for exhibiting to us variations of bright-

ness and colour, but not of position. Now this can manifestly be effected by distributing the points of an image of the object over an apparatus such as the layer of rods and cones, consisting of closely packed individuals, each of which is capable of acting on its own nervelet; or through an intermediate apparatus, which consists of channels for transmitting light as numerous as the rods and cones, each of which conducts the light from a specific point of the image to its own rod or cone, which latter may, in this case, be situated at a distance from the place where the image is formed. The first of these is the arrangement which we find in our own eyes; the other seems to be that which we find in the compound eyes of insects. Now it is doubtful whether any other machinery for bringing about the result than one or other of these two can be devised. These, at all events, are the ways in which nature attains the end; so that neither man or nature seem to have found out any other. But the position of the images, whether erect, inverted, or any other, is obviously immaterial. It is the ultimate effect within the occipital lobe of the brain that is alone essential.

SECTION II.—*Of Vision with compound Eyes.*

After these preliminary remarks on vision in general, we seem to be in a position to deal intelligently with the inquiry—How is the retinal image formed in insects? and what kind of vision do they enjoy through the instrumentality of the compound eyes with which they are furnished? These questions may be most conveniently dealt with by describing a rough model of an insect's eye. Imagine a hemispherical shell of some transparent material, *e.g.* half of a sixteen-inch globe of glass, that is, a globe of which the diameter is sixteen inches. Place your eye at its centre, and look through it at the objects of nature around you. Next, let an accurate picture of these objects be painted on the outside of the globe, so that when you place your eye at the centre you still see the same scene as before. Now let a network of scratches be made all over the painting, dividing it into patches, each of which is the size of a square quarter of an inch. This is about the size of the cross-section of a lead pencil. There will be about 6400 of these patches on the hemisphere. Next, let the paint of

each patch be removed, and a single dab of paint substituted, of
a tint and brightness which is the resultant of the part of the
picture which fell within the patch. In this way, a somewhat
coarse mosaic is substituted for the more perfect picture of the
external world previously drawn. This coarse mosaic gives a
rough imperfect representation of the external world, and repre-
sents correctly the vision which an insect has of it. The compound
eyes of some insects, especially insects that attack other insects,
have more numerous facets than what correspond to 6400 over a
hemisphere; and in such cases, the mosaic is less coarse, and the
vision is proportionately better. Thus the eye of a dragon-fly is
better represented by substituting smaller patches, each the size of
a square eighth of an inch. This increases the number over the
hemisphere to 25,600. But there is a somewhat narrow limit to
improvement in this direction, owing to its necessitating a diminu-
tion of the aperture of the lenses. The way that nature deals
with this difficulty is by increasing inordinately the size of the
compound eye of the insect out of proportion to its other features.
In this way the number of the patches, one of which is formed
by each facet, can be increased without diminishing too much the
aperture of the little lenses.

With a mosaic such as is described above, the diameter of each
patch subtends about a degree and eight-tenths ($1°·8$) at the centre
of the hemisphere. Accordingly, the interval between two objects
in nature would need to subtend an angle of about a degree and
three-quarters at the insect's eye, to be distinguishable as two by
the insect. Hence, if as far off as ten inches, the distance at
which we see most distinctly, they would need to be separated by
nearly a-third of an inch to be seen by the insect as more than one
object; while, if close to the insect, only one-tenth of an inch off,
the separation would need to be about the same as that which the
human eye is capable of distinguishing at a distance of ten inches.
Thus, the insect cannot see more detail upon its own antennæ,
close as they are to it, than we can with our naked eye. We
must, therefore, dismiss from our thoughts the mistaken impres-
sion that insects see very minute objects far beyond human vision.
On the contrary, their vision is imperfect compared with ours.
Still, it is evidently quite enough to enable a bee to be guided in
its search after honey by the markings upon a flower, or effectually

to assist a fly in its wanderings about the room, or in sopping up its food.

We have next to consider how this mosaic is formed. For this purpose let us again turn to our model. Suppose 6400 hollow conical funnels to be provided, each one inch long. Let them be slightly more than the thickness of a lead pencil at their larger end, and tapering from this down to a diameter of a sixteenth of an inch at their smaller end. Let the insides of these funnels be blackened so as to stifle any light that falls on them. Fit a small lens of one-inch focus into the larger end of each, and then pack the funnels somewhat like the cells of a honeycomb, over the hemisphere spoken above, the larger ends outwards, and the smaller planted on the middles of the little patches that were marked out on the hemisphere. The little lenses will then lie on an outer hemispherical sheet eighteen inches in diameter.
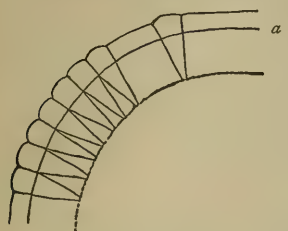
a, Outer surface. *b*, Primary surface.
FIG. 2.—THE FUNNELS OF AN INSECT'S EYE (DIAGRAMMATIC).

Let us fix our attention upon one of the little lenses, and consider how it operates. The light from distant objects in the external world would, if not interfered with, form an inverted image one inch behind this lens, that is, at the distance of the glass hemisphere, which we shall call the primary surface; but it is prevented from forming more than one patch of that image by the blackened walls of the funnel. Accordingly, only one tiny patch of the image, one-sixteenth of an inch across, is actually formed. It is formed by the light which passes the whole way down the funnel, and emerging at its end, falls on the surface of the primary hemisphere. Here it produces one little fragment of the inverted image, the rest of the image which the lens is competent to form being extinguished by the blackened walls of the funnel. In the insect's eye the small portion of the image that emerges is, no doubt, a portion of a rather indistinct image, owing to the very small aperture of the lens; but neither this nor its belonging to an inverted image is any detriment, since all the rays that go to form the little patch are transmitted to a single one of the pieces of apparatus in the insect, corresponding to the rods and cones of our eyes. They, therefore, can result in only one of the

optic nervelets being affected, and in some one definite way ; in
other words, the whole of the light forming one patch, or rather
speck, of the image can produce only one elementary visual
impression in the insect's mind.

It will be observed that the image that is formed resembles
rather a mezzotinto engraving, which consists of separate specks,
than a mosaic which consists of patches of colour large enough to
touch one another ; and that it differs from the mezzotinto in that
the specks are specks of light, instead of being, as in the engraving,
specks of shade.

If we endeavour to make out what provision is made in com-
pound eyes for enabling the insect to accommodate its vision to
varying distances of the object, we find, upon a scrutiny of the
section of such an eye, that the arrangement appears to be one
which gives to an insect the very singular power of adjusting
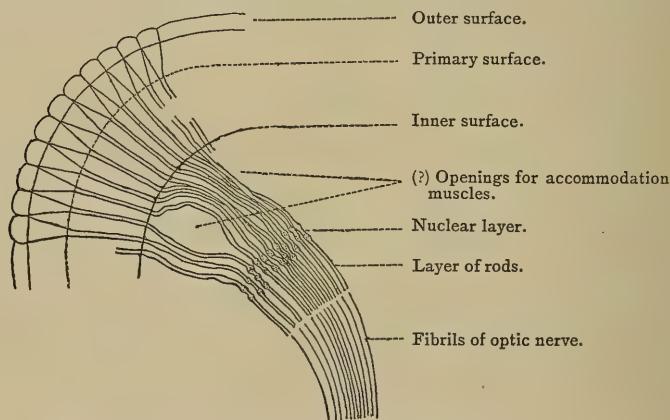
FIG. 3.—SECTION OF AN INSECT'S EYE (DIAGRAMMATIC).

different parts of its field of view to different distances, and
operates in a remarkably simple way which may be illustrated
upon our model if we add somewhat to it. For this purpose
let a third hemisphere be provided, concentric with the other
two, but smaller—suppose with a diameter ten inches across.
Let the funnels which have been spoken of, and which lie between
the outer surface and the primary surface, be made of some
extensible material, like indiarubber, their outer ends being
fastened to the lenses and their inner ends to threads of glass the
thickness of thin knitting needles, and extending, as in figure 3,

from the primary surface to the inner surface. To make it possible to do this the glass hemisphere which we have used to represent the primary surface may now be removed; it is no longer required, since its position is sufficiently indicated by the points of junction of the indiarubber funnels and the glass threads. The outer surface of our model, which carries the lenses, should be a stiff, immovable arch, but the inner surface is to be made of some material which is capable of slightly contracting. If, after constructing the model in this way, its inner surface is made to shrink a little,[1] this will pull the glass threads inwards and elongate all the indiarubber cones. In this way the narrow ends of the cones are brought farther from their lenses, into the position where the image of a near object would be formed. The model now represents the insect's eye when accommodated for the vision of near objects.

In this model the image of the outer world is formed either at the primary surface or at the inner surface, for a speck of light falling on the upper end of one of the glass threads will travel lengthwise along the thread and emerge from its lower end, being kept from escaping laterally by total reflections. Now, it seems probable that something of this kind actually occurs in the insect's eye. In fact the apparatus corresponding to the rods and cones of our eyes seems, so far as I can make out, to be situated, not at the primary surface where the image is first formed, nor even at the inner surface where the image may be reproduced in the way described above, but in a deeper situation with which the inner surface communicates only through curved transparent threadlets. Each of these threadlets seems to have a thin transparent core, and if this core be of sufficiently highly refractive material, it would, although curved, be competent to carry the light forward by total internal reflections, from the lower end of one of the glass threads to one of the pieces of the apparatus which corresponds to the layer of rods and cones in our eyes.[2]

---

[1] A diminution of the radius of the inner surface of the model to the extent of about one millimetre would effect a sufficient range of accommodation. The motion in the insect's eye may need to be more than in proportion to this, since the filaments, as well as the funnels of its eye, are probably extensible, which is not the case in the model.

[2] The light is probably carried forward most effectually where, as in the dragon-fly, the threadlets are less than a micron in section, *i.e.* not much more than the

It is, perhaps, worth observing that an eminently useful adjustment which we cannot effect seems to be possible in an insect's eye. In fact, the inner surface of our model might be drawn inwards more at one place than another; and I am disposed to think that muscles, acting on the inner surface, are in the insect so disposed as to make this possible in its eye. Now, this would effect an accommodation to the distances of objects which would differ in the different parts of the field of view.[1] Moreover, this result may be brought about in another way. The lenses and the funnels posterior to them vary in size from one part of the compound eye of a dragon-fly to another, being largest in the position which I suppose to be about the middle of the eye, and gradually dwindling to about half this size near the margin.[2] An equable contraction of the "inner surface" of such an eye would obviously effect a different accommodation in different parts of the field of view. Accordingly, in one or other of these ways, or by a combination of them both, the insect may be able to adjust one part of its field of view for near objects, and other parts for more distant ones, *e.g.* a fly may be able to view distant objects around with the utmost distinctness of which its eye is capable, at the same time that it is closely scrutinizing the details of a lump of sugar and applying its proboscis rapidly to one minute crystal after another. As the adjustment which would enable it to do this would be of service to the insect, and as the construction of its eye admits of it, it seems likely that it is one for which provision has been actually made.

On a review of the whole subject we seem to have a satisfactory

---

wave-lengths of the light that has to traverse them. Light would adapt itself to the sinuosities of such filaments, like sound in a speaking-tube.

[1] In the sections of the eyes of dragon-flies which I have examined, the filaments from the funnels down to the "inner surface" are enclosed within a sheath of fibres and are straight, but immediately after passing through the inner surface they are each apparently enclosed within a tube, and grouped in bundles, between which are open spaces which may, perhaps, in the living insect have been occupied by muscles. Muscles, in this situation, would be competent to effect the optical adjustment spoken of in the text. (See fig. 3.)

[2] The increased aperture of the lenses towards the middle of a dragon-fly's eye, and the diminished curvature of the stratum in which they lie, both conduce to make its vision more perfect towards the middle of its field of view; and as this lies in the direction of the insect's flight, the arrangement must be of advantage to it in its pursuit of prey.

general insight into the process by which vision through compound eyes is carried on. Doubtless much detailed information of the minute anatomy of these interesting structures has been reached by microscopic anatomists; but I am not acquainted with it, and have been obliged to rely on my own imperfect observations. It is, however, likely that, notwithstanding the diligence of microscopists, much still remains to be explored; and this, I hope, may be followed up more intelligently if the general optical process is understood. It is on this account that I have endeavoured to trace it out, and especially because, among my scientific friends in Dublin, there are to be found some of the most competent persons thoroughly to explore the whole of this interesting subject.

I have hitherto said nothing about vision through the isolated eyes with which insects are also furnished. They cannot, from the minuteness of their lenses, give them nearly so good vision of distant objects as man enjoys. And the limit is very possibly still more restricted by their being furnished with but a moderate number of rods and cones. It would be of interest to ascertain by observation whether this is so, and to collect such data as would enable us to estimate with tolerable exactness how far the imperfection goes.

XXVI.

ON THE POST-EMBRYONIC DEVELOPMENT OF FUNGIA. By GILBERT C. BOURNE, M.A., F.L.S., Fellow of New College, Oxford.

I am indebted to Professor A. C. Haddon for a fine collection of Fungiæ in all stages, brought back by him from the Torres Straits, an examination of which has enabled me to give a detailed description of the various phases in the life-history of this coral. For convenience sake I have adopted the following terms, descriptive of the various structures in the young and adult Fungiæ :—

Trophozooid.—The individual Caryophyllia-like form developed directly from the ovum. This may give rise by budding to one or more—

Anthoblasts, by which name the buds are conveniently distinguished from the individual which gave rise to them.

Anthocormus.—Two or more Anthoblasts united to form a stock or colony.

Anthocyathus.—The discoid Fungia form, whether free or attached, developed from a Trophozooid or an Anthoblast.

Anthocaulus.—The pedicle which carries the Anthocyathus, and, after the detachment of the latter, remains in connexion with the Cormus, or is attached to a foreign body, and usually gives rise, by re-growth, to a new Anthocyathus.

The Trophozooid may remain solitary, and give rise to a succession of Anthocyathi; more usually it gives rise by budding from the extrathecal soft tissues to a number of Anthoblasts, which form a stock or colony. Under exceptional circumstances buds may also be formed—(1) from the truncated distal end of an Anthocaulus, (2) from the scar on the aboral surface of a recently detached Anthocyathus. Longitudinal division of the calyx of an Anthoblast has also been observed.

The Caryophyllia form of the Trophozooid or Anthoblast is not long maintained, but the margin of the calyx grows outwards to form a disc-shaped Anthocyathus. This is eventually set free, and new Anthocyathi, to the number of three or four, are successively formed and detached from the Anthocaulus. In a young Trophozooid or Anthoblast there are twelve primary septa; in succeeding stages—twelve secondaries, twenty-four tertiaries, and forty-eight quaternaries are developed. The relations of the tertiaries to the secondaries and the quaternaries to the tertiaries are the same as in Stephanophyllia. Fungia cannot be placed in any of the groups Euthecalia, Pseudothecalia, or Athecalia, established by recent authors. A compact theca is present, formed partly by the union of the peripheral ends of the septa, partly by interstitial pieces uniting the peripheral ends of the septa. True epitheca is present in the Anthoblast.

The anatomy of the polype resembles that of Actinia. Typically each septum is enclosed by a pair of mesenteries; but, as in course of growth a new cycle of septa makes its appearance before the corresponding mesenteries, there are stages in which the septa are—(*a*) all entocœlic, (*b*) alternately exocœlic and entocœlic. The structures of the Anthocyathus are formed as direct outgrowths of the corresponding structures in the Anthocaulus; but the mesenteries are scarcely represented in the Anthocaulus, and, after detachment of an Anthocyathus, are formed anew in the distal end of the Anthocaulus before the outgrowth of a new Anthocyathus is externally visible.

The absorption of the corallum at the point where the Anthocaulus passes into the Anthocyathus, causing the detachment of the latter, is not effected by means of phagocytes, nor through the agency of a special tract of tissue cells. Numerous dark-staining bodies of peculiar character have been observed, but they occur in all parts of the Anthocyathus, and in many parts of the Anthocaulus, and, probably, are nutrient cells, and are not in any way connected with the absorption of the corallum. In the region where absorption of the corallum, and consequently the detachment of the Anthocyathus, takes place, the tissues undergo degeneration, and the corallum contiguous to the degenerate tissue becomes white, opaque, and brittle. The parts of the corallum which are thus altered are especially liable to the attacks of the

well-known parasitic fungus *Achyla penetrans*, which would appear to take an important share in effecting the detachment of the corallum. It seems probable that the degeneration of the tissues in the neck of the Anthocyathus gives rise to degenerative changes in the substance of the corallum in that region. The corallum in this region may be spoken of as " dead," and in the course of time would be slowly dissolved out by the action of sea-water, thus setting free the Anthocyathus; but it appears to be nearly invariably the case that this slow process is hastened by the parasite *Achyla penetrans*, which riddles the dead region of the corallum, and so weakens it that the slightest force is sufficient to set free the Anthocyathus.

The structure of the young and adult Fungia, the arrangement of the septa and mesenteries, the mode of growth of the Anthoblast, and its division into Anthocaulus and Anthocyathus, show conclusively that the adult free Fungia is an individual, and is not, as Ortmann has supposed, a colony consisting of a central nutritive person surrounded by irregularly scattered degenerate persons whose function is prehension and respiration.

XXVII.

ON THE REDUCTION OF MANGANESE PEROXIDE IN
SEWAGE. By W. E. ADENEY, Assoc. R.C.Sc.I., F.C.S.,
F.I.C., Curator in the Royal University, Dublin.

SOMETIME ago, when studying the action of potassium perman-
ganate on sewage, I noticed that freshly-precipitated peroxide of
manganese, when left immersed in a comparatively large bulk of
sewage for four or five days, becomes completely reduced to
manganous carbonate.

The reduction may be shown in an interesting way by mixing
in a large glass beaker four or five litres of sewage with a suffi-
cient quantity of a water-solution of potassium permanganate to
give it a deep pink colour. The permanganate rapidly decomposes,
and a precipitate, consisting chiefly of peroxide of manganese in
a hydrated form, collects in large flakes on the sides and bottom
of the beaker. If, now, the beaker and its contents be allowed to
stand for four or five days, the peroxide of manganese, especially
the portions deposited on the sides of the vessel, may be observed
to slowly change to a yellowish-white colour. On examination of
some of the yellowish-white substance, obtained as just described
it was found to consist of manganous carbonate, associated, as was
to be expected from the nature of the liquid in which it was
immersed, with swarms of minute organisms.

When we consider the chemical characters of the peroxide
obtained in the manner described, it seems impossible to avoid
the conclusion that it owed its reduction to manganous carbonate
or the influence of some at least of the organisms growing in the

liquid in which it was immersed, and that the decomposition is analogous in character to that which Gayon and Dupetit[1] have shown nitre undergoes, when it is present in the nutrient medium in which certain organisms are grown.

Those observers isolated from sewage two aerobic organisms, which they named *Bacterium denitrificans* α and β. By quantitative experiments, they showed that, when these organisms are grown in almost any infusion containing organic matter and also nitre, the whole of the nitrogen of the nitre is evolved as gas, and that the whole of its available oxygen is combined with carbon to form carbon dioxide. Some ammonia is formed, but it is derived, they state, from the nitrogenous constituents of the nutrient medium employed.

The authors show that the organisms will not develop in liquids free from nitrate and kept out of contact with air. They therefore regard the decomposition of the nitrate as a fermentation consisting of the direct oxidation of organic carbon at the expense of its available oxygen.

The decomposition of the nitrate may therefore be expressed thus :—

$$(1). \quad 4\,KNO_3 = 2\,N_2 + 2\,K_2O + 5\,O_2.$$
$$(2). \quad 5\,C + 5\,O_2 = 5\,CO_2.$$
$$(3). \quad 2\,K_2O + 2\,CO_2 = 2\,K_2CO_3.$$
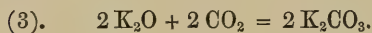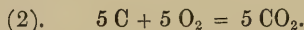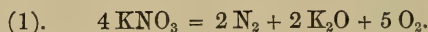
If the decomposition of the peroxide above described be regarded as analogous in character, then the whole of its available oxygen should combine with organic carbon, and manganous carbonate be finally formed, thus :—·

$$(1). \quad 2\,MnO_2 = 2\,MnO + O_2.$$
$$(2). \quad C + O_2 = CO_2.$$
$$(3). \quad MnO + CO_2 = MnCO_3.$$
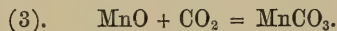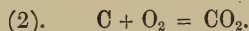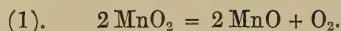
That these reactions would be attended with the evolution of a

---

[1] Ann. de la Science Agronomique, 1885, I., 226 ; also abstract Chem. Soc. Journ., XLIX., p. 823.

considerable quantity of heat, and would therefore constitute a source of considerable energy to the organisms, is evident from a consideration of the following thermal data taken from Thomsen's "Thermochemische Untersuchungen" :—

$$
\begin{aligned}
2 \, [\text{Mn, O, H}^2\text{O}] &= 189,440 \\
2 \, [\text{Mn, O}^2, \text{H}^2\text{O}] &= 232,660 \\
\hline
\text{Loss} &= -43,220 \\
\hline
[\text{C, O}^2] &= 96,960 \\
[\text{MnH}^2\text{O}^2, \text{CO}^2\text{Aq}] &= 13,230 \\
\hline
& 110,190 \\
& -43,220 \\
\hline
& +66,970
\end{aligned}
$$

Freshly precipitated peroxide also suffers reduction to manganous carbonate when it is mixed with *solid* fermentable organic matters. I have recently been able to put this to test on a somewhat large scale at some sewage purification work where manganate of soda is employed for treating the sewage. At the works referred to, the greater portion of the solid matters in suspension in the sewage are first separated by mechanical subsidence; the sewage is then mixed with a water solution of manganate of soda; the peroxide, which afterwards separates, is allowed to subside, together with matters remaining in suspension in sewage, to the bottom of the tank in which the operation is conducted. It is finally drawn off from the tank in the form of a mud. I obtained several hundredweight of this mud, and first drained it on a gravel-bed, and, when of sufficient consistence, I made it up into a large heap, and allowed it to slowly air-dry in a covered shed. After being left in this condition for about three months, I found the interior portions of the heap had assumed a grey colour, only these portions immediately exposed to the air had retained the original brown colour of the peroxide.

I detached some small lumps from the heap, allowed them to

completely air-dry, and then submitted a portion to analysis, with the following results :—

Insoluble mineral matter, ...	12·16
Moisture, ...	15·68
Organic matter insoluble in dilute HCl, .	4·00
Organic matter soluble in dilute HCl, . .	4·35
MnO, ...	24·60
CaO, ...	2·70
Fe_2O_3 Al_2O_3	10·06
MgO, ...	1·60
Na_2O, K_2O, ...	1·10
$(NH_4)_2O$, ...	0·005
NiO, CoO, ZnO, ...	traces
CO_2, ...	18·98
SO_3, ...	0·37
P_2O_5, ...	0·59
Cl, ...	trace
	——————
	100·695

It is evident from the above results that the manganese was present mainly as manganous carbonate. A careful examination was made for peroxide, but with negative results. An examination for nitrates was also attended with negative results.

No trace of sulphuretted hydrogen, or other products of putrefactive fermentation, such as are invariably met with when sewage solid matters alone are kept under similar conditions, were detected.

The organic matters associated with manganous carbonate were found to be of considerable interest. A combustion of some of the air-dried substance gave the amount of organic carbon, after allowing for the inorganic carbon, as = 4·7 per cent., and a determination of the organic nitrogen by Kjeldahl's method gave 0·67 per cent.

As will be gathered from the Table giving the results of analysis, a portion of the organic matters present was taken up by

the dilute acid employed for dissolving the substance. Practically, however, all was left undissolved when the solution was evaporated to dryness, and the residue treated with concentrated hydrochloric acid and water, in the ordinary way, for the separation of soluble silica. The organic matters which were separated in this way were brownish-black in colour, and were largely soluble in a dilute solution of sodium carbonate, giving rise to a solution of a deep brown colour. They seemed, in fact, closely associated in chemical and physical characters with the colouring matters of peat, and also with the colouring matters which are formed where soluble sewage-matters are oxidized by microbes in the presence of an excess of atmospheric oxygen. I must, however, reserve a full consideration of these colouring matters for a further communication. The influence which the peroxide of manganese appears here to exert on the products of fermentation of the organic matters with which it was associated, and the reduction and conversion into carbonate which itself undergoes, leads, I think, fairly to the conclusion that the decomposition of the peroxide under the conditions described, may be regarded as a fermentation consisting of the direct oxidation of organic carbon at the expense of the available oxygen of the peroxide ; that, in fact, the insoluble peroxide exerts, when mixed with solid fermentable matters, an influence, and undergoes a change, precisely analogous to the influence and change which nitre undergoes when present in a liquid nutrient medium in which either of the two organisms, *Bacterium denitrificans*, α and β, are allowed to grow.

I ought to state that Dr. E. J. M'Weeny, Professor of Pathology and Bacteriology in the Catholic University School of Medicine, has already commenced a bacteriological study of the organisms which are associated with the reduced peroxide which I have above described.

I cannot conclude without expressing my warm thanks to Mr. James Carson, Assoc. R.C.Sc.I., for the skilful assistance which he has rendered me in carrying out the analytical portions of the work embodied in this Paper.

XXVIII.

ON A NEW FORM OF EQUATORIAL MOUNTING FOR MONSTER REFLECTING TELESCOPES. By SIR HOWARD GRUBB, M.A.I., F.R.S.; Vice-President, Royal Dublin Society.

THE problem of mounting large reflecting telescopes satisfactorily does not appear so near to solution in this year 1894 as might be expected, considering the great strides which have been made in mechanical engineering within the last quarter of a century.

It is now about half a century since the late Earl of Rosse mounted a 6-foot reflecting telescope, which has never yet been exceeded in size, and for many years, from 1868 to 1888, the Melbourne reflector (4 feet) was the largest equatorially mounted instrument in existence.

It is only within the last five years that this has been exceeded by Dr. Common's 5-foot reflector; and in a recent paper by Dr. Common on the mounting of monster reflectors (Monthly Notices, Royal Astronomical Society, vol. liii., p. 19), he proposes to revert to the old alt-azimuth form of mounting on the ground of the immense size and weight (and consequent cost) of an equatorial that would be sufficient to carry the great weight of such a telescope.

Now, when we consider that the lowest magnifying power of an 8-foot reflector is about 480, and of a 10-foot (such as is proposed for the Paris (1900) Exhibition) 600, it will be understood how very unsatisfactory such a mounting would be for large-size telescopes.

To view objects in a telescope satisfactorily, it is necessary to bring them into or near the centre of the field of view, but even suppose we are satisfied to view them while in any part of the field of an ordinary eye-piece, the object could only be viewed in the 8-foot telescope for about 15 seconds, and in the 10-foot

telescope for 12 seconds at a time. This would render the telescope practically useless.

The larger the telescope the more important it is to have it equatorially mounted, and driven correctly by clock-work, so that the observer may watch for a favourable opportunity for distinct vision. It is to be remembered that, in the case of very large apertures, it is only in glimpses on a fine night that good definition is to be obtained; and therefore it is all the more important that the observer should have the opportunity of watching for, and taking advantage of, these favourable moments.

I am one of those who think that reflectors have not had a fair chance in the race with refractors, and I believe a great future is before them. I have therefore paid some attention to the possibilities of satisfactorily mounting reflecting telescopes of what may be called monster sizes—I mean of 8 or 10 feet in diameter;—and as our neighbours in France have announced their intention of constructing a 3-metre reflector for the next Paris Exhibition of 1900, this may not be an inappropriate time to discuss the question.

The problem to be solved is that of mounting, on an equatorial movement, a telescope of, say, 80 or 100 tons weight, so perfectly equipoised and relieved of friction that it can be conveniently manipulated and carried by clock-work, or some motive power, to follow a celestial object with such accuracy that it will not at any moment vary from its correct position by a quantity equal to the apparent motion of that object in a space of one-tenth or one-twentieth part of a second.

That the problem is one of difficulty is sufficiently evidenced by the fact that Dr. Common, who has done the latest and best thing in this way, in equatorially mounting his 5-foot reflector, practically gives up hope of success, and proposes to revert to the almost useless alt-azimuth form.

I am, however, by no means so despairing, and I believe that before long the apparently impossible will become possible, and I would venture in this present Paper to shadow forth what I believe will be found the most hopeful principle on which to mount the monster reflecting telescope.

Dr. Common himself has made a splendid advance in adopting the system of flotation of the polar axis; this principle of

flotation appears to me to be capable of further development, and I have given some thought to the matter. It is perfectly possible to make a tube for a Newtonian reflecting telescope (which is necessarily closed at the lower end) of such a weight, and with its weight so distributed that it will not only float in water submerged to a certain point (preferably near the upper end), but will be in a state of equilibrium when placed at any or in every position down to a certain angle, which angle depends on the exact outside form of the tube. For instance, if *A B* (fig. 1) be a tube closed at *B* and perfectly symmetrical round the axis *A B*, and the total weight of the tube be equal to the weight of water which is displaced when the tube is sunk to *C*, the weight of the different sections along the axis *AB*, can be so distributed that the tube will equally well remain in any other position, except it be so far turned over that the cylindrical part of the tube is lifted out of the water at one end and dipped at the other.
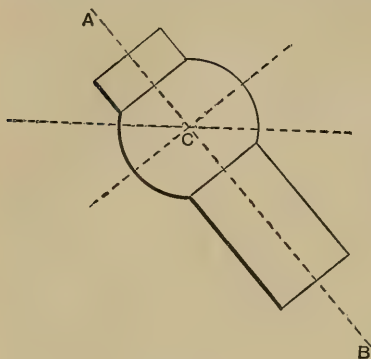
Fig. 1.

By making the spherical part of about the proportions of the figure, the tube can be depressed to within 25° of the horizon, and still remain in perfect equilibrium.

Now, suppose the tube to have a pair of trunnions attached at the water-line, and these carried on a polar axis of, say, the English type (see fig. 2), we have an equatorially-mounted telescope of any size, without any weight whatever on the bearings of the Dec axis, or, the tube may be lightened by an amount nearly equal to the weight of the polar axis, and there will then be practically no weight whatever on the bearings of that axis. So here we have a case of, say, an 80-ton telescope mounted and carried by an equatorial, but without throwing any weight whatever on that equatorial; and the force necessary to drive the instrument is independent of the weight of the telescope, and dependent only on the friction necessary to be overcome in carrying the tube at an exceedingly slow rate through the water.
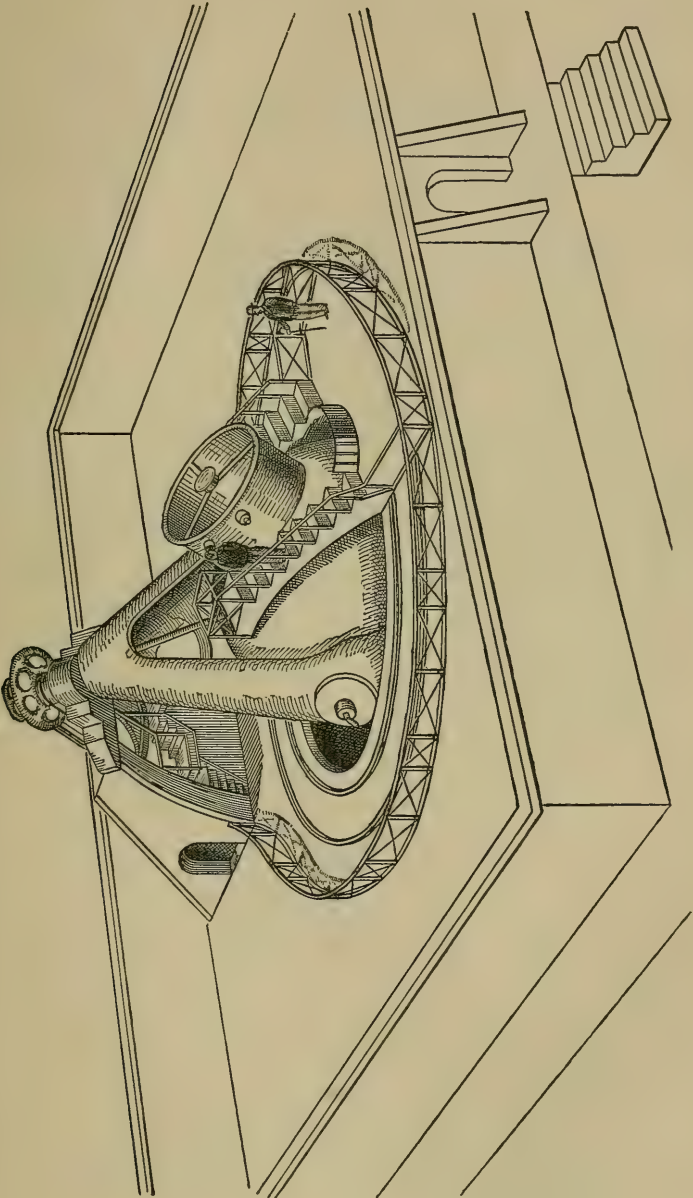
Fig. 2.

Let us inquire into any possible disadvantages that may be urged against this form of mounting:—

1st. That the temperature of the water will often be different from that of the air; and consequently that there will be a detrimental mixture, at the mouth of the tube, of air from inside the tube, which will partake of the temperature of the water, with the outside air.

This I would propose to avoid by making the tube double, with a space of some 3 inches between inside and outside tubes, hermetically closed except at the lower end, where there would be apertures in the inside envelope.

The space between the two tubes would be connected through the trunnions with an air-pump, worked by a gas or other motor, which would continually exhaust the air from between the two tubes, and thus cause a current of the outside air to pass continually down the tube and back to the pump by the space between the two tubes. This would keep the temperature of the inside tube and the air in the tube constant with that of the outside air.

2nd. The limited range of the equatorial. I have stated that the instrument would be in perfect balance down to 25° from the horizon. If desired, though no longer perfectly balanced, it can be used lower by employing a chain or wire rope connected between the lower end of the tube and the upper end of the polar axis, and the amount which the instrument would be out of balance, between 25° and 20°, would be very trifling.

Again, it will not be convenient to use the instrument within some 15° of the Pole. It could be planned to go somewhat closer, but when it is considered that nine-tenths of the work required to be done can be commanded by this instrument, it is clearly better to design it to do that nine-tenths well than to strain it into doing another 5° that would only be useful on very rare occasions.

3rd. It may be urged that the friction of the water will prevent the rapid setting of the instrument.

In a telescope of this size all the motions would be effected by motors of some description, guided by the observer from a commutator-board at the eye-end, and there would be no difficulty in setting the telescope quite as quickly as could be expected, considering its great size.

4th. It may be objected that currents will be set up in the water by the moving of the telescope, which currents will affect the steadiness.

No doubt this will be the case to some extent, but these will soon subside, and the motion necessary for following the stars will be so slow that no perceptible effect of this kind will be felt from it.

As to convenience in getting at the eye-end, there need be no difficulty whatever in this form. As the eye-piece is only about 15 feet from the centre of motion, the movement of the observer is never more than 3 feet per hour. By means of a platform such as that shown in fig. 2, running on rails, and quite independent of the instrument, the eye end is readily accessible at all times. To overcome the rotation of the tube as the instrument moves in right ascension, I would pierce the tube for eye-pieces every 30° round its circumference, and mount the flat mirror and cell in a collar so as to enable it to be readily rotated through intervals of 30°. By these means the image of the celestial object to be observed could be sent through either or any of the perforations of the tube, and the observer always observe in the direction most convenient to himself.

XXIX.

ON THE GREAT METEOR OF FEBRUARY 8th, 1894. By
PROFESSOR ARTHUR A. RAMBAUT, D.Sc., F.R.A.S.

I THINK it will be of interest to the Society to lay before it the facts relating to a great meteor which appeared on February 8th of this year, as far as I have been able to ascertain them.

This remarkable object attracted the attention of thousands of people at various places over a region containing nearly 100,000 square miles, from Whitby in Yorkshire to London, and from Ballinasloe to Chelmsford in Essex.

Even at night it does not often occur that a meteor is seen over such an extended tract of country; but to have been so widely conspicuous within a few minutes of noon, on a day when bright sunshine almost universally prevailed, the meteor must have been one of very unusual dimensions.

At three minutes after noon, mean Dublin time, on the day in question, I happened to be standing in the grounds of the Observatory at Dunsink, when suddenly my attention was drawn to a brilliant object, which first appeared at an altitude of 25° (as nearly as I could estimate it) above the horizon. It fell in a vertical direction, and disappeared behind some trees at a height of, as nearly as possible, 5° above the horizon. To me it appeared of a distinctly greenish tint. The motion was not very rapid, but the phenomenon was so sudden and unexpected that I made no attempt to estimate the duration of its flight.

On account of the exceptional brilliance of the phenomenon, I put a notice of it in some of the daily papers, and in reply have had accounts from a very large number of people who happened to see it in other parts of this country and in England. Most of these accounts are, however, of such an indefinite character as to be of little or no use in determining the path of the body.

I may, perhaps, take this opportunity to point out that observations of meteors should be principally directed to obtaining estimates, with as high a degree of accuracy as possible, of the altitude and bearing of the object at epochs during its flight, which can afterwards be identified. At night it is best to note its position at first appearance and at disappearance, or at the moments when explosions take place, with reference to the stars which lie along its track. In the daytime its position must be referred to terrestrial objects, such as trees or houses. The observer should also note the exact spot on which he stands, so that he can subsequently determine the direction of the meteor accurately with the proper instruments.

To determine with precision the length of time for which the meteor remains visible is more difficult. Of course it is impossible to get out a watch and to compare it with sufficient rapidity, and the usual course is to repeat some familiar piece of poetry all the time the object is in view, noting the exact syllable at which it disappears. If then the same passage is afterwards repeated before a clock, the duration of the meteor's flight can be very approximately obtained.

The observer ought to devote his principal attention to the *bearing* of the object at the beginning and end of its flight. From this datum alone, as observed at two different stations, it is possible to determine the region over which the meteor passed. In order to determine its height in miles above the Earth's surface it is, of course, also necessary to know the *altitude*, but a single reliable observation of this sort is sufficient for our purpose, whereas it is absolutely necessary that we should have the bearing determined at two stations, at least, before we can decide as to the track of the body.

Accounts of this meteor have reached me from the following places:—

IRELAND.

Dublin.	Templeogue.	Dundrum.
Rathgar.	Clondalkin.	Kilcock.
Monkstown.	Malahide.	Ballinasloe.
Clontarf.	Raheny.	Edenderry.
Blackrock.	Drumcondra.	Glaslough.
Kingstown.	Terenure.	Belturbet.
Sandycove.	Glenageary.	Drumree.

ENGLAND.

Holyhead.
Berkhampstead.
Shrewsbury.
Buntingford.
Bedford.
Rugby.
Coventry.
Ampthill.
South Woodford.
Oakham.
Downham Market.
Stevenage.
Saffron Waldron.
Gloucester.
Hull.
Gosberton, near Spalding.
Chipping Norton.
Canningtown, London E.
Leicester.
Ely.
Loughborough.
Swindon.
London.
Swavesey.
Birmingham.

Bicester.
Woburn Sands.
Droitwich.
Great Malvern.
Bardney.
Mildenhall.
King's Lynn.
Hertford Heath.
Canes, near Harlow.
Gamlingay.
Loughton.
Wylde Green, Birmingham.
Buckden.
St Ives (Hunts).
Hertford.
Northampton.
Martley.
Sheffield.
Loddington.
Hempstead.
Pershore.
Great Thurlow.
Cheltenham.
Banbury.
Pondsbridge.
Biggleswade.

Dudley.
Camberley.
Doncaster.
Wellingborough.
Aylsham.
Llandilo.
Stoke Newington.
Worcester.
Brentwood.
Manchester.
Beverley.
Chester.
Oxford.
Berriew.
Leeds.
Chelmsford.
Fulbourn.
Warmington.
Derby.
Hereford.
Maldon.
Wimbledon.
Cheadle.
Maidenhead.
Devizes.

From the accounts which have reached me of the altitude and azimuth of the meteor at its first appearance, I have computed that it was first noticed when over a spot situated in longitude 2° 54′ W. and latitude 53° 40′, and at a height of $59{\cdot}4 \pm 4{\cdot}1$ miles.

For computing the position of the meteor at disappearance I have only three observations of azimuth and two of altitude available. These agree, however, fairly well in indicating a position in longitude 1° 35′ W. and latitude 53° 35′. The two observations of altitude at the time of the meteor's disappearance place it at a height of $13{\cdot}4$ and $14{\cdot}4$ miles respectively.

With regard to the velocity I have no very reliable data.

The time of flight has being variously estimated at from 1 to 5 seconds.   One observer states that it remained visible from 15 to 17 seconds, but he is quite unsupported by others in giving it such a long life.   Taking 3 seconds as a mean of the estimates—which will agree well with my recollection of the appearance—we find, since the length of the track was 57 miles, that the object was moving with a mean velocity of 19 miles per second, or very approximately that of the Earth in its orbit.

We may say, therefore, that the object was first seen at a height of very nearly 60 miles, almost vertically over the estuary of the Ribble, at a point between Southport and Preston, and about one-quarter of the distance from the former town.   That it travelled across Lancashire and part of Yorkshire at an average rate of 19 miles per second, and finally disappeared from view at a height of 14 miles, over a spot between Wakefield and Sheffield, at about three-fifths of the distance from the latter.

It is usual in an inquiry of this sort to seek the direction in space from which the meteor came—*the radiant*, as it is called—and this is obtained by producing backwards the track in which it was seen to move.   In this case, however, such an investigation is out of the question, since there is evidence to show that the path was of a curvilinear form, while there are not sufficient observations available for determining the shape of the curve.

In most cases the path of a meteor deviates but little from being a straight line, the velocity imparted to it by the Earth's attraction being but small as compared with the velocity with which it is moving through space.   In the case before us, however, since the portion of the Earth's surface over which the meteor passed was moving towards the west with a velocity of nearly 19 miles per second, or nearly the whole relative velocity observed, we see that this was probably a very slowly-moving body in space before it came under the influence of the Earth's gravitation. Under these circumstances it is not to be wondered at that the path in which it moved was found to be considerably curved. Thus, Mr. John Pycock, of Gamlingay, Cambridgeshire, describes it as "making a long curving sweep through the sky."   Mrs. A. W. Wills, Wilde Green, Birmingham, saw it "descending rapidly in a curve, not vertically."   Miss Laura Wood, Berkhampstead, says that it "fell in a graceful arch"; while Mr.

Edward Coleman, of Ampthill, Bedfordshire, describes it as twisting towards the east before disappearing.

The mode of the meteor's disappearance is somewhat doubtful. To most observers it seemed to vanish while still at a considerable height, without sparks or noise. To Mr. J. R. Hird, of Bardney, Lincoln, however, it "appeared to break up in four or five pieces, which also vanished instantly." Mr. Paul de C. Potter, King's Lynn, describes it as having "dispersed just as it was about to fall," and Mr. Thomas Cole, of St. Ives, Huntingdonshire, saw it " explode amidst a magnificent shower of sparks."

Although I sent a notice to the English Papers, directing attention to the fact that the meteor was last seen over South Yorkshire, and suggesting that inquiries should be made as to whether anything unusual had been observed there in the way of a fall of stones or iron, I have not heard of any such occurrence having been noted, and it is probable that the body was wholly dissipated at a height of about 14 miles, where it is last reported to have been seen.

XXX.

ON A METHOD FOR COLOURING LANTERN SLIDES FOR SCIENTIFIC DIAGRAMS AND OTHER PURPOSES. By PROFESSOR J. A. SCOTT, M.D.

THE method of colouring the gelatine film with the anilin and other dyes is not new; but in the form in which it has been prac- tised hitherto, the dyes have been thickened and used on the sur- face after the manner of ordinary pigments.   In the method which I have adopted, the gelatine is stained simply without the addition of any medium.   In order to make the colour run evenly, the gelatine film should be moist, but not wet with drops of water— the most favourable condition being immediately after the final washing of the slide is completed, and the film allowed to drain ; but if this should not be convenient, the slide may be placed in water for a quarter of an hour, and then drained.   If the slide has been dry for some days or weeks, a greasy film appears on the surface, which should be removed with a little methylated spirit before soaking in water.

In this damp condition the colour will be absorbed slowly and evenly, when a dilute solution of the dye is applied with a brush. The colours show no tendency to run.   The intensity of colour depends primarily on the strength of the original solution, and secondly on the length of time it is allowed to act on the gelatine, so that local shading can be produced by keeping the brush in one spot for a longer time.   Should the trial be unsatisfactory from any cause, the colour can be completely removed by soaking in clean water for some time, and the slide can be re-painted.

If the colours are placed simply on the gelatine, almost any of the dyes can be used ; but some are more likely to fade than others, and a few are more easy to lay on evenly.   If, however, the colours have to be mixed, either before painting or by overlapping on the gelatine, it is important to remember that some of the dyes act

chemically on each other, and produce new bodies, which may be granular or of a new colour.   Ordinarily, yellow and blue make green : thus, indigo carmine, when mixed with either picric acid, napthal yellow, or tartrazene yellow will produce various shades of green ; but if methylene blue be mixed with the same yellows, a purple colour is produced with picric acid, an orange with napthal yellow, and a green with tartrazene yellow.

The colours which I have found satisfactory both as to mixtures and ease of laying on evenly are—*eosin, tartrazene yellow, vesuvin, indigo carmine*—with *soluble blue* as a useful alternative for the last for bright green, when mixed with tartrazene yellow. Methylene blue, methyl violet, and iodine green did not appear to be satisfactory colours.

As some of the anilin dyes are liable to fade on exposure to light, I painted a test slide with parallel lines of the colours just mentioned and others, and having covered one half of the plate with black paper, placed it in a lantern illuminated with a Brockie-Pell arc lamp.   The light was maintained at intervals, as was found convenient, until a total of five hours had been reached, when it was found that eosin, methyl violet, and iodine green faded most ; others slightly, and tartrazene yellow and indigo carmine very little, if at all.   Subsequently, a similar plate of eosin, atlas scarlet, and two varieties of erythrosin was illuminated for five hours before the arc-light, in the hope that one of them would prove more permanent than eosin.   They were, however, very similar in their permanence.

One sample of erythrosin, obtained from Schuchardt of Görlitz, seemed a trifle better than the other make of erythrosin and the other colours.

It is difficult to find a dye so brilliant as eosin, even erythrosin being much more purple ; so I have recommended eosin as one of my selected colours, notwithstanding its defects ; it must, therefore, be applied a little more intensely, if the slide is intended for much use.   Very faint pinks will fade completely in a few minutes in the lantern, while, on the other hand, I have slides in use for years which have been rather strongly coloured, and show no appreciable amount of fading yet.

Coloured outline diagrams may be made on clear glass by using, with an ordinary pen, solutions of the dyes which have been

thickened with dextrine to give a body to the colour : about 10 per cent. dextrine is sufficient ; the glasses should be well cleaned before writing. In a compound diagram, if the first colour be allowed to dry, other colours may be rapidly written over the former ones without risk of removing them. For these inks any colour may be used. Iodine green and eosin inks make a particularly brilliant contrast. A very good dark ink, not absolutely black, may be made from Antoine's " encre noire," made slightly alkaline with ammonia, and thickened with 10 per cent of dextrine.

XXXI.

ON A MOUNTING FOR THE SPECULA OF REFLECTING
TELESCOPES, DESIGNED TO REMOVE THE IMPEDI-
MENT TO THEIR BEING USED FOR CELESTIAL PHO-
TOGRAPHY AND SPECTROSCOPY. By G. JOHNSTONE
STONEY, M.A., D.Sc., F.R.S., Vice-President, Royal Dublin
Society.

I.—INTRODUCTION.

REFLECTING telescopes have conspicuous advantages over refractors,
accompanied, however, by one defect which has greatly interfered
with their usefulness. One of the advantages they have is that
they are less costly. The glass of which specula are constructed
need not be of good quality, and is therefore cheap : moreover the
figuring of the one surface of the speculum of a reflector, although
it requires to be effected with about six times the accuracy that is
needed for any one of the four surfaces of the object-lens of a
refractor, is easier and therefore less expensive than the very
difficult task of combining the conditions which must be fulfilled by
the four surfaces of a good object-glass. A speculum is therefore
cheaper, perhaps about one-fourth of the cost of an equally good
object-lens. But their great excellence lies in their optical per-
formance; from their being absolutely free from the chromatic
nuisance, and, moreover, from their spherical aberration, if corrected
at all, being corrected for rays of all refrangibilities. This would
give the reflector an overwhelming advantage over the refractor,
and especially in photographing the heavens, or in using the spec-
troscope, were it not for their one defect—that their line of colli-
mation is apt to shift. Owing to this serious defect they can only
be used for celestial photography and spectroscopy by persons
whose powers of manipulation are altogether exceptional.

The object-lens of a refracting telescope may be supported
entirely by its edge, and is always so supported. This is suffi-
cient, although, when the telescope is pointed towards the zenith

the lens sags down, owing to its own weight, and assumes a very sensibly different shape from what it has when the telescope is pointed horizontally. In fact this distortion of form, although considerable, does not sensibly affect the image. That this can be the case may be easily seen by remembering that the waves of light which constitute the rays *a, b, c, d, e* must reach the point *o* in exactly the same phase, or very nearly the same phase, in order that they may be able to unite and form an image there.
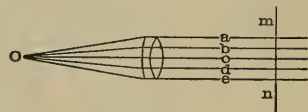
Fig. 1.

Now this condition will be fulfilled if these rays all take the same time to travel from a wave-front *mn* outside the lens, to *o*. Each of the rays passes first through air, then through the lens, and then through air. Light travels slower in glass than in air; and accordingly the requisite condition will be fulfilled if the form of the lens obliges those rays whose course is less bent to pass through a duly regulated greater thickness of glass. The waves of the central ray have the shortest distance to travel, but find the thickest part of the lens in their path. They are therefore most retarded. The rays *b* and *d* have farther to travel, but meet with a thinner part of the lens and are less retarded, while *a* and *e* which have the longest journey are still less retarded; and if the lens has been properly figured they all reach *o* at the same instant of time.

Now let the telescope be pointed upwards. The lens, as it is supported only by its rim, sags down in the middle by its own weight. Each ray, except those at the margin, has now a little farther to travel in air from *mn* to the lens, but it has a little less to travel from the lens on to *o*; and on the whole the time spent upon the part of its journey which is in air, is almost exactly the same as before. Again, the glass, though it sags down a little, has not become anywhere sensibly thicker or thinner. Each ray traverses almost exactly the same thickness of glass as before, and occupies the same time in doing so. Accordingly, the air part and the glass part of the journey of each ray occupying almost exactly the same time as before, the whole time spent by each ray in travelling from *mn* to *o* is almost exactly the same, whether the telescope is pointed horizontally or vertically.

The case of the speculum is very different. Here the journeys

are altogether in air; and if the mirror were supported only by its edge, it would sag down when pointed towards the sky, the central ray would then have farther to travel to reach the mirror than the marginal rays, and again farther to get from the mirror to *o*. The wave front of the central ray will accordingly reach *o* too late to unite with the waves

Fig. 2.

travelling along *a* or *e*. These will already have passed *o*.
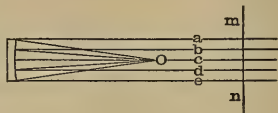
Hence a speculum must be kept from sagging: and to this end must be supported continuously over its whole back, and with such extreme delicacy that all parts of the back of the mirror shall be equally pressed.

If the mirror could be kept horizontal, it might be floated on mercury; but as during the use of the telescope it has to be sloped into different positions, a layer of the delicate springs of which flannel consists has been used for the support of smaller specula up to a 15″ or 18″ aperture, and the mechanical contrivance called a bed of levers for the larger ones, the edge of the mirror being supported in some way which allows its back to lean freely against the bed of levers, or layers of flannel, as the case may be. Whether it be the levers or the layers of flannel that are used, they inevitably yield when the pressure upon them varies, and it becomes difficult to prevent the line of collimation—that is, the optical axis of the mirror—from shifting a little relatively to the tube of the telescope, when the telescope is carried from one position to another—so difficult that it is only in the hands of very skilful manipulators, like Dr. Isaac Roberts, that celestial photographs can be satisfactorily taken with reflecting telescopes. Nevertheless, when they are so taken, they surpass those which can be produced by refractors.

2.—The Proposed Mounting.

The following seems to be a way in which this difficulty can be entirely gotten rid of, and specula made available both for celestial photography and spectroscopy, and in astronomical instruments of precision:—

Let the mirror *M* be made the front of an airtight cell, such as that represented in the diagram, which consists of three chambers

A, B, C, of which A and C communicate with one another, and contain compressed air, while B is open to the atmosphere and contains a regulator which causes the pressure within A and C to vary by the right law when the telescope is moved from one altitude to another. This regulator consists of m, a corrugated disk like the cover of the vacuum-chamber of an aneroid barometer, and n a weight which leans against m, and is kept from slipping sideways by wires p, q, r, of which p and q are shown in the figure. If the
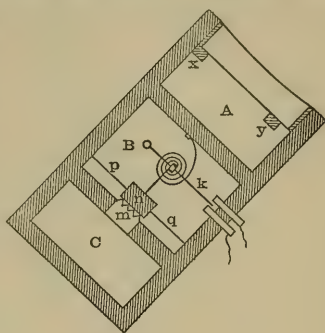
Fig. 3.

pressure within the cells C and A (which communicate with one another) becomes too great for the proper support of the mirror, n will move forwards and cause the index k to make electric contact with one of two studs, in consequence of which a valve is opened that lets some of the imprisoned air escape. If, on the other hand, the pressure is too small, n moves backwards, contact is made with the other stud, and a passage is opened between a gasometer holding compressed air and one of the chambers A and C. This regulator will vary the pressure within the chambers A and C when the telescope is moved about, and will cause it, in each position of the telescope, to settle down to that which is precisely the right amount to support the mirror without flexure, at that elevation.

The mirror may be brought into a pre-determined position by being placed just in contact with studs x, y, z, and then cemented round the edge by some cement, like Archangel pitch, which will adapt itself to the mirror and hold it firmly without straining it. If necessary, the front of the cell may be strengthened by flanges to prevent distortion when the cell is placed on its side.

Mounted in such a cell, which can be rigidly fixed within the tube of the telescope, it is anticipated that the line of collimation of the instrument will be as fixed, and may be as much depended upon as that of a refractor; and if this be so, reflecting telescopes may be made available for photographing the heavens and photographing the spectra of stars, in the hands of any astronomer engaged in this class of work.

Another advantage which this arrangement has is, that it will enable reflecting telescopes to be sloped downwards, and used in such a siderostatic instrument as that which Sir Howard Grubb made for Queen's College, Cork. To slope the telescope downwards it is only necessary to place the airtight compartments *A* and *C* in communication with a partially exhausted gasometer and the open air, through the passages which before connected it with the open air and a gasometer of compressed air. If an instrument of this kind is to be used for photography, the telescope is to be directed towards the South pole and fixed immovable; while the only parts to be carried round by the polar axis are the siderostatic flat mirror, mounted on a cell of a new pattern, and the photographic plate-holder, or these with an eye-piece to enlarge the image. The weight to be carried round may be still further reduced, and at the same time some light saved, since the siderostatic mirror, *M*, and its supporting cell, *C'*, may be perforated in the middle, and the photographic apparatus, placed below them, on the polar axis.
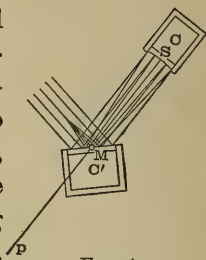
Fig. 4.

The mounting of such an instrument would be so much less expensive than that of an equivalent equatorial that the whole cost, including that of the siderostatic mirror, would probably be less, while the instrument itself would be very much more easily manipulated than the equatorial. Such an instrument should produce good photographic work, now that large flat mirrors of great excellence can be produced. For accurate spectroscopic work the arrangement seems to offer even greater advantages, for the spectroscope, as well as the telescope, may be absolutely fixed, and the only thing that needs to be moved is the siderostatic mirror.

There remains a point to be considered. A large mirror cannot be removed and replaced upon its bed of levers. It must be ground and polished upon it, and allowed to continue afterwards upon it in the telescope. Can the corresponding arrangement be made with the new cell while manufacturing the mirror? I think so. What is required will be to place the mirror in a cell (not necessarily the same cell) filled with compressed air or with

water under pressure, and suitably to counterpoise the grinder or polisher. Perhaps the usual mode of counterpoising will be found sufficient, or if necessary a light cell of the new kind may be adapted to the grinder or polisher, and the whole counterpoised, so as to secure a perfectly clean cut over the surface of the mirror, without pressure upon one part more than another. One other point seems worth noticing : that if the figure of the mirror, when finished, be slightly too hyperbolic or elliptic, it may perhaps be brought nearer to the true form by a slight increase or decrease of the pressure of the air upon its back, which could be easily secured by dividing the front chamber of the cell into two compartments with a regulator acted on by a spring between them.

It may perhaps be well to mention that the pressure of the air to be stored in the gasometer needs only to be of moderate amount, and can be easily provided by an automatic water-dropping arrangement. Thus to support a glass mirror five inches thick, a maximum pressure of only one inch of mercury is requisite—*i.e.* one-thirtieth of an atmosphere.

On the whole there seems reason to hope that reflectors may, with advantage, be substituted for refractors in photographing the heavens, for spectroscopic work, and in some instruments of precision ; that the instruments will be cheaper, and the work produced by them distinctly better.

<center>XXXII.</center>

ON THE SELECTION OF SUITABLE INSTRUMENTS FOR
PHOTOGRAPHING THE SOLAR CORONA DURING
TOTAL SOLAR ECLIPSES. By ALBERT TAYLOR,
A.R.C.Sc. (Lond.), A.R.S.M., F.R.A.S.

THE great success obtained by the various parties which observed
the Total Solar Eclipse of 1893, April 15–16, is extremely
valuable, not only as giving us a very complete record of the form
and structure of the Solar Corona at the time of the eclipse, but
also as indicating the best methods, both photographic and instru-
mental, for future work in the study of the phenomena of eclipses.
Although full descriptions and discussions of the results have not
yet been published, sufficient is known to enable us to form definite
conclusions on certain hitherto disputed points ; and as the next
observable total solar eclipse is on August 8, 1896, and the organi-
zation of expeditions to observe it should be commenced at once,
I have thought it might be useful to briefly indicate, in this paper,
what I think should be the main considerations guiding the
organisers and observers of future eclipses.

There is such a great variety in actinic brightness of the various
phenomena of an eclipse that it is practically impossible to get all
of them by one exposure on a photographic plate. As I have
previously pointed out (" Observatory," vol. 16, p. 95), we may
roughly divide the phenomena into four main divisions—the
chromosphere and prominences, the inner corona with polar rays,
the middle corona extending from 10′ to 30′ from the limb, and
the faint extensions which have been traced, visually, some 5° from
the limb, and which are only very slightly more actinic than the
surrounding sky. There are very few difficulties in photographing
the first three of these portions, but there has been considerable
discussion as to the best method of photographing the faint
external extensions of the corona. The eclipse of 1893, April 15–16,
has added materially to our knowledge on the latter point, and
has also assisted us in indicating the direction of future work for
the brighter parts of the corona.

The instruments previously used had been of comparatively small aperture and of moderate focal length, the limits of six inches aperture, and six or seven feet focus being very rarely exceeded. Professor Pickering, at the eclipse in California, 1889, January 1, used a photographic object-glass of 13 inches aperture and 16 feet focus (the longest focal length up to that time), and Father Perry, at the eclipse at Salut Isles, French Cayenne, 1889, December 21–22, used a mirror of 20 inches aperture and 45 in. focus; but these were exceptional instruments.

In 1893, April 16, four stations were occupied, and the eclipse was successfully photographed at all of these. Professor W. H. Pickering was at Minasaras, in Chili, and used a 5-inch object-glass of about 48 inches focus, stopped down to 3 inches aperture, and a 20-inch mirror of 45 inches focus. Professor Schœberle, of the Lick Observatory, was at Mina Bronces, in Chili, and he and his assistant, Mr. W. F. Gale, of New South Wales, used two instruments, one of 4·96 inches aperture, and 46 feet focus, and the other of $6\frac{1}{2}$ inches aperture and 6 feet focus. At Para Curu, in Brazil, I used two optical combinations, one a 4-inch photographic lens of 60 inches focus, and the other a 4-inch lens of about the same focus, but fitted with a triple cemented negative enlarger of 8 inches negative focus, which enlarged the image 3 diameters, thus corresponding to 4 inches aperture and 15 feet focus. At Fundium, in West Africa, Serjeant J. Kearney, R.E., used a double camera exactly similar to mine in Brazil. Comte de la Baume Pluvinel, of Paris, who was also at Fundium, West Africa, used nine different objectives (mounted on one stand), all of sensibly the same focus, $1\frac{1}{2}$ metres (4 feet 10 inches), and with apertures varying from 155 mm. to 5 mm. Other instruments were used at the various stations, but these are the chief ones, and those from which valuable scientific results were obtained. The principal departures from ordinary practice were the long focal-length instruments, 46 feet in Chili, and 15 feet in Brazil and Africa, and the exceptionally small apertures, 5 mm., of Comte de la Baume Pluvinel, in Africa.

One of the most disputed points in eclipse photography has been as to the proper exposure to obtain the faint extensions of the corona without fogging the plate by the skylight. Captain Abney has shown that we may look upon a photograph as representing 200 different shades; or, in other words, that on a

correctly exposed and developed negative a difference of $\frac{1}{2}$ per cent. in the intensity of light can be detected. It should therefore be possible, by correct exposure, to detect the corona on the sky when the skylight forms $99\frac{1}{2}$ per cent. of the light, and the corona $\frac{1}{2}$ per cent. The problem is to obtain negatives showing this difference, and two diametrically opposite opinions were held as to the best method of securing this. The American observers and Comte de la Baume Pluvinel held that short exposures and slight photographic action were necessary, whereas most English authorities held that it was only by long exposure and great photographic action that we could hope to secure the faint extensions.

The photographic action on a plate is the product of three factors—the effectiveness of the lens, the duration of the exposure, and the sensitiveness of the plate. The effectiveness of a lens or mirror was defined by the International Photographic Congress at Paris as $100\,\dfrac{a^2}{f^2}$, where a is the aperture, and f the focal length of the optical instrument; so that in comparing the photographic action on plates taken with various instruments, the formula becomes $100\,\dfrac{a^2}{f^2}\,t.\,s.$, where t equals the time of exposure, and s is the sensitiveness of the plate. Assuming plates of normal sensitiveness used throughout, we get $100\,\dfrac{a^2}{f^2}\,t$ as the formula for comparing the photographic actions on the various plates used for the corona; and the application of this formula to the eclipse plates of 1893, April 15–16, gives very interesting results.

With the English instruments exposures of 2, 5, 15, 20, 50, 120, and 150 seconds were given; and applying the formula we get :—

4-inch lens, with enlarger :—

1 second = ·044.

2 seconds =	·088
5 ,, =	·222
15 ,, =	·666
20 ,, =	·888
50 ,, =	2·222
120 ,, =	5·333
150 ,, =	6·666

4-inch lens, 60 inches focus :—

1 second = ·444.

2 seconds =	·888
5 ,, =	2·222
15 ,, =	6·666
20 ,, =	8·888
50 ,, =	22·222
120 ,, =	53·333
150 ,, =	66·666

An examination of my photographs taken in Brazil shows that there is a steady increase in the extension of the corona on the plates of the first series, in which the photographic actions increased from ·088 to 6·666, although the latter suffered slightly from sky fog; but in the second series there is a steady increase up to 20 seconds, and practically no gain is shown by the 50, 120, and 150 seconds, while the two latter plates have suffered very much from sky fog, and the inner portions of the corona are hopelessly burnt out. The best all round result for the inner and middle is obtained by a photographic action of less than 1, and there is a loss in external corona when the photographic action reaches 22.

With Professor Schœberle's instruments a similar result is obtained. The 4·96-inch object-glass, of 46 feet focus, gives a photographic action of ·0086 for 1 second exposure, and the photographs taken with this instrument, in which the photographic action never reaches 1, are magnificent for the inner and middle corona, while they also show some portions of the external corona. With the 6½-inch lens of 6 feet focus, the photographic actions were :—

(1 second corresponds to a photographic action of ·766.)

$$\text{Instantaneous, say } \tfrac{1}{50} \text{ second,} = \quad ·005$$

1	second	=	·766
2	seconds	=	1·532
4	,,	=	3·064
8	,,	=	6·128
10	,,	=	7·660
16	,,	=	12·256
32	,,	=	24·512

He finds the best picture of the external corona is given by 16 seconds, corresponding to a photographic action of 12·256, a greater photographic action than this resulting in sky-fog and loss of detail in the external corona. The best photographic action found by Professor Schœberle falls between the English best (8·888) and the first English result in which loss by sky-fog is found, and indicates that an exposure of 29 or 30 seconds with the 4-inch lens of 60 inches focus is about the limit of good results. To go beyond this is to lose detail.

Comte de la Baume Pluvinel had his various photographic cameras arranged to have photographic actions varying in such a manner that the greatest was 1000 times that of the least. He finds, as a general result, that the best all-round negative is given by a photographic action equal to 4: but this does not agree with the results obtained in Chili and Brazil. A probable explanation is, that whereas in Chili and Brazil the sky round the corona was perfectly clear during totality, at Fundium there was light haze in the sky. M. Deslandres says there were "faint clouds," and these would necessarily be illuminated by the corona, and would give a far brighter sky than was found in Chili and Brazil. Comte de la Baume Pluvinel, at Salut Isles, in 1889, Dec. 21–22, found, using photographic actions varying from 185 to 13, that the best result was given with an action over 13 and under 32, this agreeing very nearly with the results found by Professor Schœberle and myself in 1893. I have at present no precise details of Professor Pickering's exposures, and so cannot get his photographic actions, but the comparison of his results with those of Professor Schœberle and myself will be extremely interesting in settling this important point.

There can be little doubt that the idea that long exposures and great photographic action are necessary for the external portions of the corona must be abandoned; and in devising instruments for future eclipses, there is nothing to be gained in this direction by the use of photographic actions exceeding 15 or 16. This will enable instruments of much greater focal length to be used for future work. An instrument working at $\frac{a}{f} = \frac{1}{10}$ will secure all the external corona in about 15 or 16 seconds, and one at $\frac{a}{f} = \frac{1}{25}$ will secure everything in about 100 seconds.

In addition to a lens working at this ratio I would recommend the use of a 12-inch object-glass of 40, 50, or 60 feet focus, which would enable pictures of the corona to be obtained on such a scale that the image of the moon would be over 4, 5, or 6 inches in diameter. Short exposures with this would give the inner and middle corona with all the beauty and delicacy obtained by Professor Schœberle in Chili; and 100 seconds' exposure would give nearly all the corona that is within reach of the photographic method of attack

in the present state of photography. That such lenses can be easily and efficiently mounted and used was clearly shown by Professor Schœberle; and it seems to me, after the results of 1893, that it is only by such object-glasses as I have indicated that such an important occurrence as a total solar eclipse should be attacked in future, if we wish to add to our knowledge of the corona.

There does not seem to be any great difficulty in mounting these long-focus instruments. Professors Todd and Bigelow at Cape Ledo, S. W. Africa (1889, Dec. 21–22), adopted a tripod stand, with a sand piston for one leg, which was so arranged that the shortening of the leg as the sand ran from under this piston caused the telescope to be moved to follow the sun during the eclipse. As this necessitated the use of a long tube, supported on what looked to me an unstable mounting which would certainly shake in a wind, I do not think any great success can be anticipated from this form; certainly the risks of failure would be greater than if some form of fixed tube were adopted.

We can use a fixed tube in any of three ways:—

(*a*) With a heliostat, in which a mirror is carried on a polar and declination axis, and is driven by clock-work, so as to throw the sunlight always in the same direction, *i.e.*, into the horizontal telescope tube.

(*b*) With a mirror mounted on a polar axis driven by clock-work, the tube of the telescope being placed in the meridian, and inclined at an angle equal to the latitude of the place of observation.

(*c*) On the plan adopted by Professor Schœberle, with the tube adjusted in altitude and azimuth so as to point to the sun at mid-eclipse, the photographic plate being moved so as to follow the sun during totality.

The first two of these plans are open to the objection that the sun's image, as reflected from a mirror, rotates as the polar axis carrying the mirror is moved in right ascension. This rotation would amount to over 20 minutes of arc in 100 seconds' exposure, and would probably be sufficient to blur the finest details of the inner corona. The first is open to the additional objection that with a heliostat-mounting the motion of the polar axis is communicated to the mirror by means of a jointed rod, and the motion through this is a series of slips, and not the perfectly even motion

that is absolutely essential for the best work. These two objections practically dispose of the first method ; and the rotation of the corona introduced by the second method is a serious objection.

The chief objection to Professor Schœberle's plan is that the image of the sun travels across the field of the object-glass during the eclipse, and that it is only at mid-eclipse that the plate is exactly in the optic axis of the object-glass. As the movement of the sun in 3 minutes of time is about 45 minutes of arc, and the field of a good object-glass is practically perfect over at least 2°, and very good for 1° on each side of this, this objection is not a serious one, for we could rely on getting good definition during a 6 minutes eclipse, and we rarely get such duration for these phenomena. The only moving parts in this arrangement are the plate-carrier and plate, and these are extremely light, so that very perfect motion can be given by a very simple clock, or by some simple water-motor similar to that adopted by Professor Hale, of Chicago, in his spectroheliograph. With the apparatus used in Chili Professor Schœberle gave exposures of 32 seconds, and obtained perfect pictures. The instrument of the future for obtaining the inner and middle corona at eclipses will probably be some simple apparatus founded on this principle, in which a long-focus object-glass will be used, and small photographic action obtained on the plate.

[279   ]

XXXIII.

ON DERIVED CRYSTALS IN THE BASALTIC ANDESITE OF GLASDRUMMAN PORT, CO. DOWN. By GRENVILLE A. G. COLE, M.R.I.A., F.G.S., Professor of Geology in the Royal College of Science for Ireland.

THE author described a large composite dyke showing at this point a band of andesite on each of it, from 4 to 17 feet wide, and a more recent dyke of eurite in the centre, 36 feet across. The eurite includes numerous blocks of andesite, and sends off veins into it; but the pyroxene and glass of the latter rock have become remelted at the contact, a delicate interpenetration of the two magmas has occurred, and the porphyritic crystals of quartz and pink felspar from the eurite are found completely surrounded by the dark andesite. Thus a pre-existing rock comes to include crystals derived from one that has subsequently invaded it, and hand specimens, without study in the field, would be of a most misleading character.

XXXIV.

ON THE FOSSIL-FISH REMAINS OF THE COAL MEASURES OF THE BRITISH ISLANDS. PART II.—ACANTHODIDÆ. By THE LATE JAMES W. DAVIS, F.G.S., F.L.S., F.S.A., &c.

XXXV.

ON EOZOONAL STRUCTURE OF THE EJECTED BLOCKS
OF MONTE SOMMA. By PROFESSOR H. J. JOHNSTON-
LAVIS AND DR. J. W. GREGORY, F.G.S.

THE authors show that the limestone blocks, of Mesozoic age, in
Monte Somma have frequently become metamorphosed into
crystalline masses consisting of alternating bands of calcite and
various silicates. The authors regard the silica, magnesia, &c.,
as derived from the igneous rock by chemical interpenetration
and interaction. Where the silicate, as often happens, is olivine
(montecellite), or a pyroxene, a complete simulation of the struc-
ture of *Eozoon Canadense* is produced. The layers of silicates
occur parallel to the surfaces of any igneous vein that may have
intruded into the limestone, and they become closer to one another
in the areas farther removed from contact. The " proper wall,"
the " stolons," and in places the " canal system " of *Eozoon* are
recognizable under the microscope; and the authors adduce
evidence to show that the typical eozoonal limestone of Canada
may have arisen similarly as a product of contact metamorphism.

THE

SCIENTIFIC PROCEEDINGS

ROYAL DUBLIN SOCIETY.

CONTENTS.

The Authors alone are responsible for all Opinions expressed in their Communications.

Royal Dublin Society.

EVENING SCIENTIFIC MEETINGS.

THE Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and ready for transmission to the Editor.

XXXVI.

THE AUTOMATIC IMAGE-FINDER. By THE REV. RICHARD C. BODKIN.

1°.—*Construction of the Instrument, and the Principles upon which it is based.*

The instrument which I have the honour of bringing under the notice of the Royal Dublin Society is called the Automatic Image-Finder. This name but very inadequately expresses the end and scope of the instrument; still I could find no better.

The real object I had in designing and constructing the instrument is threefold :—

1. To show where the image of any object placed before any lens *must* be formed ;

2. To *prove* that the image is found there ; and

3. To help to explain the construction of the various optical instruments in use, such as the microscope, telescope, camera, and projection lamp.

Thus the Automatic Image-Finder is essentially a teaching instrument.

The construction of this instrument is very simple, and depends on a few elementary principles.

1. It is well known that the image of an object is invariably seen where the rays proceeding from that object meet, or seem to meet, *e.g.* if the rays meet at A (fig. 1), we see the image at A ; if they meet at a we see the image at a ; and if they do not meet at all, but merely seem to meet at a', then we see the image at a'.

2. The rays proceeding from any point in an object *always* meet (or, if not, at least seem to meet) at *some point or other along*

the secondary axis drawn from that point. Thus, if *A* is the point in the object, the image of that point will be found somewhere or other along the line *AA* (fig. 1). If *a* is the point, its image will be found somewhere along *aa* (fig. 1).
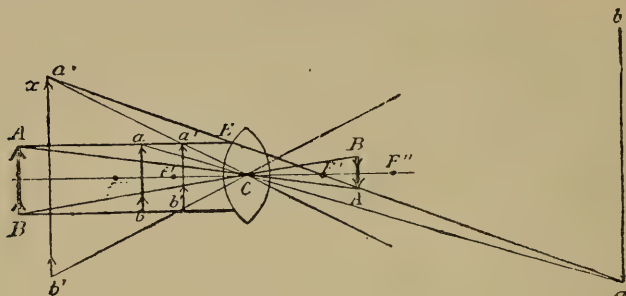
FIG. 1.

Keeping these two principles in view we may proceed.

Since we always see an object where the rays proceeding from that object meet, or seem to meet, and since they always meet (approximately), or seem to meet, at some point on the secondary axis, evidently the all-important point is to find where *they meet the secondary axis.*

Now this is found very simply, for if we can show where any one ray cuts the secondary axis, all others must cut it at the same place. Now it so happens that it is a matter of extreme simplicity to show where a ray drawn from the object parallel to the principal axis must cut the secondary axis from that point. And this is the great fundamental principle to be attended to in the construction of the instrument.

The secondary axis from any point passes as a straight line through the centre of the lens. Consequently we have one point (viz. the centre of the lens) in this line always fixed, and so this point acts like the centre of a circle round which the line revolves. It may therefore be aptly represented by a pivot and a line revolving round it. This may indicate all the positions that the secondary axis can occupy, no matter where the object may be. We can therefore easily find the various positions of one of the lines.

Now for the position of the other line, viz. the line proceeding from the same point in the object, and drawn parallel to the

principal axis. The position of this line presents no difficulty whatsoever; in fact it is absolutely *fixed* and *constant*, no matter what the position of the object may be. This of course is at once quite clear when stated, for a ray parallel to the principal axis *must* of necessity pass through the principal focus, and so we have two points fixed in this straight line (viz. the point where it cuts the lens and the principal focus), and therefore the position of the line is determined. In fact, to indicate its position, we have only to draw a straight line from the point where the parallel ray cuts the lens to the principal focus, and produce this line indefinitely. In a word, one of the lines (viz. the parallel line) is constant in position, and the other moves up and down along it. It therefore only remains to determine the position of one of the lines at any moment, and that is easily done, since one of the points is fixed, and acts as the centre of a circle, and the other is immediately determined by the position of the extremity of the object as it moves along in its course.

In order to apply these principles with greater ease, attention is here directed to figure 1.

Let *AB* represent the object; then the rays drawn from the extremities of the object and passing through the centre of the lens, will proceed as straight lines, as seen in the figure (lines *AA* and *BB*).

Now another straight line drawn parallel to the principal axis, and meeting the lens at *E*, must pass through *F*, and so we have its position determined.

From a consideration of these principles we arrive at a very simple rule for drawing the images of any object placed anywhere before a lens (or mirror). It is this :—

1. From the extremities of the object, draw secondary axes (or straight lines passing through the centre of the lens).

2. From the extremity of the object, draw a straight line parallel to the principal axis and cutting the lens.

3. From the point where this line cuts the lens, draw a straight line through the principal focus, and produce it indefinitely.

4. Where this line cuts the secondary axis there is the image

Now the Image-Finder is merely an embodiment of this rule in simple mechanism, and so it furnishes an easy and rapid means of drawing images, no matter how the position of the object may vary.

To see this more clearly we have only to look at the figure of the instrument (fig. 2). Here we have the object, viz. the arrow *AB*.
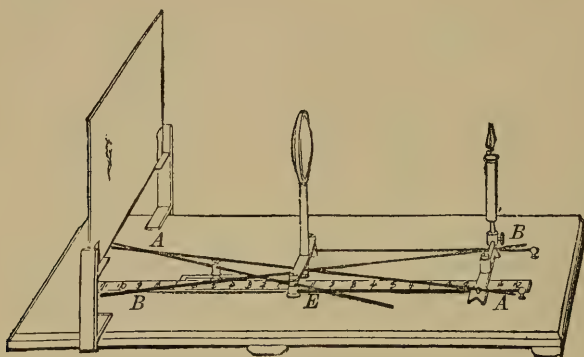
Fig. 2.

1. From the extremities of this arrow (viz. *A* and *B*), we draw secondary axes represented by the wires *AA* and *BB*, and these revolve on a pivot which represents the centre of the lens.

2. From the extremity of this object or arrow we draw a straight line parallel to the principal axis. This is represented by the parallel wire *AE*.

3. From the point *E* where this wire cuts the lens, we pass a straight wire *AE* through the principal focus.

4. Where this wire cuts the secondary axis *AA* there is the image, *v.g.* at *A*.

To be brief, the Image-Finder consists of an arrow or object capable of moving backwards and forwards along two parallel wires, which represent the parallel rays proceding from the object. From the point at which one of these parallel rays meets the lens, proceeds a ray passing through the principal focus; this indicates the course pursued by the parallel ray after refraction. Lastly, from the extremities of the object pass two straight lines through

the centre of the lens; these represent the secondary axes, and by their motion round the pivot (caused by the mere approach and recession of the object) they indicate the various positions that must be assumed by the secondary axes, corresponding with the various positions of the object. Now according to the principles above laid down, where the lines (in their motion) intersect the refracted parallel ray, there is the image.

2°.—*How to work the Image-Finder.*

In order to work the Image-Finder, and see how it enables us to know the position of the image at any moment, and to discover the laws of lenses, we have only to slide the arrow or object backwards and forwards, and then note where the rays intersect : there then is the image. The mere motion of the arrow causes the secondary axes to travel in and out, and to assume their proper positions according to circumstances, thus intersecting the refracted parallel ray (which is constant in position) at various points, showing thereby where the image is, whether it is real or virtual, larger or smaller than the object, erect or inverted.

To discover the laws of lenses by means of the Image-Finder we have only to observe that—

1. If the object or arrow is at infinity (or as far away as possible), the rays meet at f, and so the image is there : it is real and smaller than the object.
2. If the object is at $2f$, we find that the rays meet at $2f$, and so the image is there. Further we see that as the rays really meet, the image is real, of the same size as the object, and inverted.
3. If the object is at f the rays go out parallel, and so never meet. In this case the image is said to be at infinity.
4. If we place the object anywhere *between* infinity and $2f$, we observe that the rays really meet somewhere between f and $2f$. Consequently the image is there ; it is real, smaller than the object, and inverted.
5. If we place the object anywhere between $2f$ and f, we note that the rays really meet only between $2f$ and infinity. Therefore the image is there ; it is real, larger than the object, and inverted.

Lastly, if we place the object between f and the lens, we find
that the rays diverge on the far side, and can only be
made to appear to meet on the opposite side of the
lens. Where they appear to meet, there is the image;
it is virtual, larger than the object, and erect.

Should we now desire to use the instrument for another lens of
different focal length, we have only to move the nut representing
the principal focus to the required position in its slot, and then
clamp it there, and move the object as before.

If we wish to employ the instrument for the demonstration of
the properties of concave lenses, we have only to change the
position of the principal focus, and bring it to the front of the lens,
as seen in the figure (fig. 2). Now withdraw the wire passing
through the former principal focus, and insert it in the moveable
nut at the far side, and also in the extremity of the section of the
lens. This gives us the new position of the parallel ray after
refraction through a concave lens. Move the object backwards
and forwards as before, and you can discover for yourself all the
laws and properties of concave lenses. In this case you will find
from the instrument that the image is always virtual, smaller
than the object, and erect, no matter what the position of the
object.

NOTE.—In the case of virtual images with convex lenses, in
order to find their positions, the rod passing through the extremity
of the lens and the principal focus must be slid through the holes
in which it fits, and so brought to the front of the lens. Still, as
before, where this line intersects the principal axis, there we have
the image.

This instrument, with very slight alterations, and worked on
the same principles, illustrates and proves all the properties of
concave and convex mirrors.

3°.—*Experimental Proof of the Laws of Lenses.*

The second end to be secured by the use of this instrument
is to prove experimentally that the images really are formed
at the points indicated. This is done in the simplest possible
manner. Over the arrow, a source of light, such as a candle, is
fitted; over the section of the lens, a glass lens of the given focal

length is fixed; and at the intersection of the rays a screen is placed to catch the image of the candle. Now, by moving the arrow in order to catch the image, the screen must be placed at the intersection of the rays, and nowhere else, thus proving experimentally the truth of the above principles, and the correctness of the working of the instrument.

4°.—*Explanation of the Construction of Optical Instruments by means of the Image-Finder.*

Lastly, the Automatic Image-Finder enables us to explain with ease the construction of the various optical instruments. All we have to do is to state precisely what we desire to get, and then apply our principles and our instrument to secure it.

For example, suppose it is required to construct a projection apparatus, what is wanted is an *enlarged real* image. Now, to secure this, the object must be placed *outside* the principal focus, else a virtual image would result; and since the image is to be larger than the object, it is found by moving the arrow that it must be placed between f and $2f$.

In a word, we see that a projection apparatus consists of a double convex lens of moderate focal length, the object being placed between f and $2f$.

Again, if it is required to find out what the construction of the microscope is, there must be a virtual image, and it must be larger than the object. This granted, it follows at once that it must consist of a convex lens, for no other lens gives an image larger than the object (in a double concave lens the image is always smaller than the object). Now since the image is to be virtual and the lens convex, the object must be placed inside the principal focus and only a little inside, else the image is not as large as possible. All this is clearly seen by moving the arrow in the instrument into various positions.

The telescope, camera, &c., admit of a similar easy explanation by means of this instrument.

XXXVII.

THE OCCURRENCE OF SEICHES IN LAKE DERRA-VARAGH, CO. WESTMEATH, 1893, 1894. By J. R. H. MAC FARLANE, Staff-Commander R.N. (Retired).

[COMMUNICATED BY PROFESSOR D. J. CUNNINGHAM, M.D., F.R.S., HON. SEC., R.D.S.]

Towards the close of the last century, attention seems to have been first drawn to, and observations made of, phenomenal changes of the level of the water in many of the Swiss lakes ; these alterations consisting of a series of rising and falling water occurring at indefinite periods, the whole movement occupying different spaces of time, varying from ten minutes to nearly an hour; the time so occupied being apparently dependent on the positions where the observations were taken on the several lakes.

This complete movement of rise above, and fall below, mean level has been termed a seiche.

The amplitude of a seiche is the extreme difference of level so produced.

The duration of a seiche is the time in seconds from the moment when the water is at mean level, until it is again at mean level, after passing through one maximum and one minimum.[1]

There would appear to be no records of observations made of seiches in any of the lakes of Great Britain or Ireland, but the non-existence of these alterations of level must not therefore be assumed, as they may be of such rare occurrence, or the rise and fall of so slight a character, that they have hitherto escaped notice.

The observations made at Lake Derravaragh, although unavoidably incomplete, leave no doubt as to the existence of seiches

---

[1] See "Lake," by J. Y. Buchanan, Esq., F.R.S., in *Encyclopædia Britannica*, 9th ed., vol. xiv., p. 220.

on that lake; later on I shall endeavour to show the difficulties in obtaining satisfactory results.

Until the alterations of the level of the water in Lake Derravaragh first came under my notice, seiches were quite unknown to me. I must therefore approach the subject with diffidence, giving, as fully as possible, the results of the observations made in the order in which the seiches occurred, and afterwards stating any ideas deduced from them.

I may premise that the house occupied by me, during the time these observations were being taken, was situated about twenty yards from the edge of the lake, and therefore in a most favourable position for observing; also that, with a view to noting the rise and fall of the lake for fishing purposes, I had placed a batten, marked in feet and inches, on one of the piles of an old pier; this batten, and the gauge which afterwards replaced it, being situated on the weather side of the lake with respect to, and in perfect shelter from, the prevailing winds.

1st Observation.—When going out in a boat on the lake, on the afternoon of the 3rd October, 1893, I noted that the level of the lake, then only slightly above its lowest during summer, was standing at half-an-inch above the lowest mark on the batten; returning about two hours later the level was half-an-inch below the same mark. Puzzled by this change of level of 1 inch, in such a short period, I carefully watched the batten until dark, from 5^h 10^m, to 6^h 25^m, during which space of seventy-five minutes there occurred three complete movements; two falling and one rising, or about twenty-five minutes to each movement, the amplitude being two and a half inches.[1]

The batten giving very rough results, I constructed a gauge which would rise and fall with the water, and a pencil attachment registering the amplitude; this enabled me, on the next day, to take a number of observations, but the change of level was then subsiding, the amplitude being only 1 inch, and the duration of the seiche thirty-six minutes. Gradually the movement became less, until about 4 p.m., when it entirely ceased.

---

[1] Although, in the definition of a seiche, already given, the time is said to be expressed in seconds, for want of delicate appliances I can give nothing less than half a minute, except when as a result of the mean of several observations.

It may here be remarked that during the time these observations were being taken, on the 3rd and 4th October, there was no wind.

In attributing, as I did, these changes of level to seismal influences, it would appear that the same impression was also first entertained by previous observers; the theories now held in connection with them are briefly as follows:—

I. That they are caused by downward rushes of wind on the surface of the lake, accompanied by changes of barometric pressure.

II. Dr. Forel attributes seiches to local variations of atmospheric pressure giving impulse, the effect of which would be apparent for a long time as a series of oscillations. He adds, however, that he attributes seiches having a greater amplitude than 1·5 metres to earthquake shocks.[1]

III. In 1881, Mr. Plantamour, an authority on this subject of seiches, assured the writer of the article in "Encyclopædia Britannica" that he was utterly at a loss for a satisfactory explanation of their causes.

IV. From the observations of Jallabert, Bertrand, Saussure, and Vaucher the following law, connecting seiches with movements of the barometer, has been deduced. The amplitude of seiches is small when the atmosphere is at rest; the seiches are greater the more variable is the atmospheric pressure; they are the greatest when the barometer is falling.

2nd Observation.—The level of the lake having been carefully watched subsequent to the changes observed on the 4th October, it is improbable that any variation took place until the second observations, which are as follows:—

During the night of the 7th and morning of the 8th December, a heavy gale was blowing from the N.W., the barometer standing at 29·20[2] in the morning. Between 11 a.m. and noon the lake was rising and falling steadily, the amplitude of the seiche being 5·8 inches; this amplitude was reduced to 4 inches at 4 p.m.

---

[1] Le Léman; Monographie limnologique par F. A. Forel, Lausanne; F. Rouge, 1892. Note:—The Bibliography is at p. 455, and the chapter on Limnologic gives all that is known about seiches.

[2] Barometer readings reduced to sea level.

From the mean of a number of observations the duration of the seiche was 39 minutes; and it was observed that the time occupied by the rising was less than that of the falling in the proportion of about 8 to 11; *i.e.* the time of rising occupied about 16 minutes and falling 22 minutes; this was also noticed in subsequent observations.

9th December.—Calm weather; amplitude of seiche 4·25 inches. Duration of seiche (mean of fifteen observations), 37·2 minutes. Barometer in the afternoon 29·5 rising.

10th December. — Barometer 29·20 amplitude of seiche in the forenoon 1·5 inches, increasing to 3·1 inches in the afternoon. Duration 39 minutes.

11th December.—Barometer 29.45 ; greatest amplitude during the night 3·1 inches, decreased to 1 inch in the morning.

12th December.—Barometer 29·60 ; amplitude about 0·5 inch.

From the 9th to 12th December, calms and light breezes with fine weather generally prevailed; but from the 13th to 17th, the lake was rising steadily from heavy rains; and in this condition the character of the seiches was entirely altered, and no satisfactory observations could be taken.

3rd Observation.—On the morning of January 27th, it was blowing in heavy squalls from the S.W., and the lake was rising and falling too quickly for observation ; but towards the afternoon, the wind having shifted to N.W., and somewhat subsided before dusk, the rise and fall had become steady and a few observations were taken :—Amplitude 5·1 inches; duration about forty minutes ; barometer 29·50 inches.

I should feel inclined to divide the seiches occurring on Lake Derravaragh into two classes.

I. Gradual rise and fall, when observations of amplitude and duration of seiche may be recorded.

This class appears to occur only when the lake is otherwise at rest, or rather when it is not receiving any accession of water from rainfall, and during the year that I remained at Lake Derravaragh was only noticed on three occasions.

It has been previously stated that on the 3rd and 4th October the weather was calm ; during the 8th December blowing a gale ; on the 9th of December again a calm ; and on the 27th January,

1894, a gale subsiding; so that there is some difficulty in understanding in what manner the seiches occurring on those several days could have been influenced by wind.

The barometer was not observed during the October seiches, but on all other occasions of their occurrence a low barometer was registered.

II. What I would term the other class of seiches occurred frequently during the many heavy westerly gales of winter, at which time the level of the lake was being continually altered by rains, and the seiches then assumed a totally different character, the rise and fall being no longer slow and steady, the water rushing upon, and receding from, the shore in the form of waves. The gauge, situated on the weather shore, and in perfect shelter, showed these variations as a quick pumping, making observations of duration impossible, although nearly 6 inches of amplitude was frequently registered.

Characteristics of the shores in the immediate neighbourhood of the spots where observations are taken, most probably govern both amplitude and duration of a seiche, but the duration so affected may be fairly constant at each station where observations are taken, although the amplitude may differ considerably on different days.[1]

On referring to the accompanying plan of Lake Derravaragh, it will be seen that the observation spot is somewhat peculiarly situated as regards its surroundings : to the west and north-west the hills about Knockbody rise directly behind the house, and on the opposite side of the arm of the lake, at less than 400 yards distance, Knockross springs abruptly from the lake.   To the south-westward of the house, the land becomes somewhat lower (about 100 feet above the lake) ; and in gales from that quarter, the wind, blowing across the lake, impinges on the steep side of Knockross, and is deflected back on Knockbody (*see* dotted line) with such violence that it becomes, under those circumstances, a bad lee-shore for a boat.   It will thus be seen that the observation spot is apparently contained in an approximate right angle, formed by the advancing and deflected wind.

I have already alluded to the difficulties in obtaining complete

---

[1] "Lake," *Encyclopædia Britannica*, 9th ed., vol xiv., p. 220.

observations of seiches; if they came in due course, as in the case of an eclipse of a heavenly body, there would be no difficulty in obtaining observers for a number of stations on a lake, in which case some result, as to the effect of the surroundings of the dif-

LAKE DERRAVARAGH.

Soundings in feet, low water, Summer level.

Height 210 feet above sea level.

Area 3051 acres,

Heights of hills given above lake.

Observation spot ⊙

Scale of Irish miles.

Scale of English Statute miles.

ferent stations might be arrived at; but when a seiche may occur at any time it renders it almost impossible to obtain synchronous observations except at considerable expense. Lake-dwellers might be roused to take an interest in the subject, but, even then,

simultaneous observations could never be satisfactorily carried out, unless, perhaps, the dwellings were connected by telephone or telegraph, as an observer at a station on a part of the lake, subject to large amplitudes, would observe a seiche that might be totally missed at another station where the amplitude was slight Self-registering gauges might be used, but a number would be required for simultaneous observations on a lake ; the clockwork movement would need attention, and specially fitted protection from the weather, this all becoming a costly experiment.

At Lake Derravaragh, at first, the theory that seiches might be due to seismal influence, appeared to be not altogether devoid of foundation. The abrupt manner in which the hills rise from the southern part of the lake seemed to point to a great depth of water ; and local rumour currently reported that at the foot of Knock Eyon the lake was 500 feet in depth, or as deep as that hill is high above it. From the soundings taken it will be seen that the deepest water 89 feet, at low water of summer, is actually at the foot of Knock Eyon ; but this depth is really very little in excess of the depths generally surrounding it, and the bottom is singularly flat, and consists of, or is thickly covered by tenacious mud.

I believe that, in the cases of some other lakes where seiches have been found to occur, attempts have been made to connect a periodical rise of an algæ to the surface, with the changes of level. From my experience, it appears that Lake Derravaragh " purges," as it is locally termed, at all seasons of the year, *i. e.* large quantities of algæ rise to the surface, rendering the water turbid to the depth of a foot or more, and should a strong breeze be blowing at the time, large collections of the bright green sub-aquatic plant may be found in all the indentations of the lee shore. Although I have noted it as being on the surface prior to the occurrence of a seiche, it was so frequently to be seen, that it is impossible to form any connection between them.

On examination[1] this alga was found to be *Cœlosphærium Kützingianum* (Näg) a plant which had been found in some parts of Ireland by Dr. John Barker, and shown by him at the Dublin Microscopical Club on 19th November, 1868. It differs from the

---

[1] Professor Fred. O. Bower, D.SC., F.R.S., Glasgow University, kindly examined and identified this plant.

common form of Volvox, the clusters or groups of cells, which form the families, being more or less lobated or constricted, and showing a decided but very gentle independent motion of an oscillatory character, giving the idea of the existence of cilia, although none could be discovered.[1]

Another somewhat phenomenal occurrence on the shore of Lake Derravaragh is seen in a small portion of a covert of Knockbody. During summer rains, or when the atmosphere is heavy with warm moisture, large volumes of steam, resembling smoke, issue from about the tree tops, but only in a circumscribed area of about an acre in extent. When seen under favourable circumstances, this presents a very curious spectacle, as if large fires had been kindled under the trees; the dense steam, rising in volumes at times, again dying down, having every appearance of smoke.

Local opinion is divided on this matter; the shaft of an old mine; fairies lighting fires; or a small mouth of Hades being the most favourite explanations.

The cause, without doubt, is warm air condensing over a spring of very cold water situated in that particular part of the covert.

A traveller in North America assures me that on many an occasion a similar spectacle was there hailed with great delight, manifesting, as it did, the presence of a cold spring.

It is highly probable that seiches occur on many, perhaps on all, lakes; but that in the majority of cases the amplitudes are so slight that the occurrence escapes notice; this is greatly borne out by the fact that it was only due to the careful watching of a batten, specially put up, that the seiches on Lake Derravaragh were ever noticed, although having, as far as at present known, an amplitude reaching 6 inches.

Before concluding this Paper I should wish to mention a phenomenal rise and fall of the river Shannon which I observed subsequent to writing the preceding notes.

I was fishing on the river about eight miles above Lough Derg, and happened to notice a stake, standing up from the bottom of the river, with its head showing about 3 inches above the water. A very short time afterwards my boatman drew my attention to

---

[1] See *Quarterly Journal Microscopic Society*, 1869, p. 197.

the fact that the stake was covered, remarking that the river appeared to be rising very rapidly ; not long after about 3 inches of the stake was again visible, and later on I again saw it covered. I had left home the night before in pouring rain, with a low and falling barometer ; but had no instrument of the kind with me.

In a river, controlled as the Shannon is, by gates or sluices, it may be possible that the rise and fall was due to their influence ; but it is to be doubted if two successive rises, such as I observed, could be caused by them. At that time I was leaving for another part of the river, otherwise might have made more observations ; but it now appears to me to be a matter for consideration as to what effect a seiche occurring, say, on Lough Ree, above where I observed this rise and fall, would have on the river, *i. e.* would each rise on the lough send down more water ? Again, suppose a seiche to occur on Lough Derg, in the other direction, what would be the effect, if any, on the river ?

Mention has already been made of the influence of the surroundings of a station on amplitude and duration of a seiche ; if, however, it could be shown that the total effect could be observed in a river, flowing in or out of the lake, the element of surroundings might be eliminated, as the river should give the mean of both amplitude and duration of the seiche for the whole lake.

While the cause of seiches remains practically unknown, except that they appear to be usually accompanied by low barometric readings, there is much room for various conjectures, but I venture to hope that a more general knowledge of their existence may induce many, having opportunities, to keep a watchful eye for their occurrence.

To give satisfactory results, synchronous observations are indispensable, with characteristics of the land surrounding the stations, and, in addition to amplitude and duration of the seiche, the barometer should be carefully noted ; also wind ; and if deflected by land, as in the case of the observation spot on Lake Derravaragh. Soundings of the lake should be obtained ; perhaps, temperature of the water ; also if a rise of algæ to the surface accompanies a seiche. It would also be an interesting matter to know whether the rise and fall is simultaneous on the whole lake, or if the water is rising at one station and falling at another at the same time.

XXXVIII.

ON *PUCKSIA MAC HENRYI*, A NEW FOSSIL FROM THE CAMBRIAN ROCKS OF HOWTH. By PROFESSOR SOLLAS, D.Sc., LL.D., F.R.S.

(COMMUNICATED BY PERMISSION OF THE DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEY.)

THE barrenness of the rocks of Howth and Bray in organic remains is rendered rather more than less surprising by the undoubted fact that living organisms were not entirely absent from the seas in which these rocks were deposited. This is proved by the occurrence in rare localities of such problematical forms as Oldhamia, and still more conclusively by the innumerable worm-borings, which traverse the brilliantly coloured sandstones of the cliffs, near the Needles.

Worms naturally suggest the contemporary existence, in some place or other, of a great variety of lower forms of life both animal and vegetable ; but of the remains of these scarcely any direct indications have as yet been discovered in our district.

The nature of the rocks is generally not ill-fitted for their preservation. Fine grained slates which have retained such delicate markings as those of Oldhamia, might fairly be expected to present us with some remains of the skeletons of graptolites, brachiopods, or trilobites, if any of these had lived in association with Oldhamia. That no trace of these or any other organisms, except worms, has hitherto been discovered, in spite of the most careful searching, seems open to only one explanation : and one is led to suppose that the Cambrian sea around Dublin, was for some reason or other, during the greater part of its existence, an almost lifeless area.

The fewer the fossils, the more strenuous must be our search for them ; and I have now to describe a curious structure, which I

found while in the company of my colleague, Mr. MacHenry, at Puck's Rocks, Howth, close to the spot where the late Dr. Kinahan discovered specimens of Oldhamia, and in the same slates that furnished me with certain spherical bodies, suggestively similar to Radiolaria. The new fossil presents itself as long, narrow, thread-like markings (fig. 1), which stand out in slight relief on the weathered cleavage faces of the rock, from which they are further distinguished by a difference in appearance due to difference in material, since the threads consist chiefly of quartz, with which is associated a small quantity of iron pyrites. The slate is of exceedingly fine texture, and greenish grey in colour: its cleavage planes are coincident, or nearly coincident, with the original planes of lamination. The threads are confined to one particular band of slate not more than eight inches in thickness, and in this are only found through a narrow tract some two or three feet in width, where, however, they are very abundant, so that on breaking the slate open, numbers will be seen on every fresh cleavage plane.
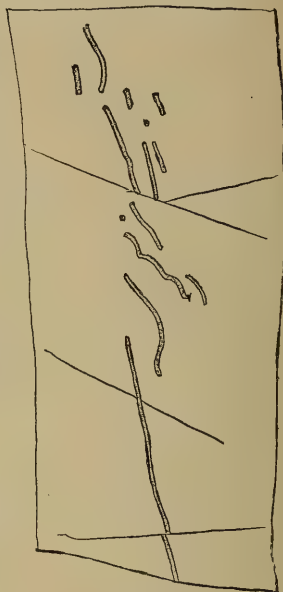
Fig. 1.

Surface of a slab of slate bearing *Pucksia Mac Henryi*. Nat. size.

The threads are of uniform breadth, from 0·5 to 1·25 mm. across, and of indefinite length up to 5 or 6 cm.: for a centimetre or two they may preserve an almost straight course, but usually they run in a gently undulating fashion, making now and then a sudden turn, and sometimes apparently plunging abruptly inwards across the cleavage planes. Down the middle line of each thread, runs a longitudinal depression, bordered on each side by swollen margins, and the whole is crossed from side to side by numerous fine and close transverse ridges and furrows.

Slices showing longitudinal sections may be readily prepared for microscopical examination by splitting off a thin lamina along the cleavage, and grinding it down to the requisite thinness: transverse sections must be cut in the usual way with a lapidary's wheel.

Sections in both directions present a median and two lateral regions corresponding to the longitudinal depression and lateral
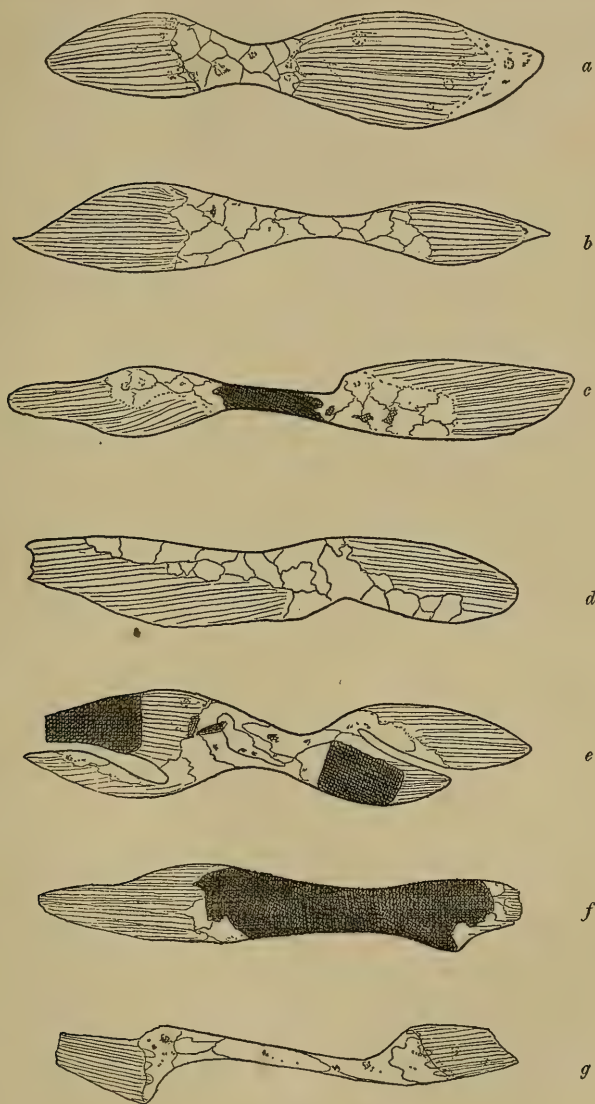
Fig. 2.
Transverse sections (× 6o).

ridges already mentioned. The transverse sections (fig. 2) have usually a lemniscate form, two broad lateral lobes being united by

a narrow central bridge : this and the proximal part of the lobes consists of an irregular mosaic of quartz grains, while the remaining distal part of the lobes is composed of fibrous quartz, the fibres of which proceed from the granular mosaic outwards to the margins of the lobes, lying in close parallelism to the cleavage planes of the slate.   The distinction of the fibrous from the granular quartz is clearly marked, and is sometimes emphasised by the presence of minute black granules, apparently of iron pyrites, which are dotted along the line of junction.   Similar granules not infrequently occur arranged in circles within the fibrous quartz, as though surrounding spherical growths of chalcedony.   Pyrites in larger or smaller crystals, sometimes partially converted into limonite, may take the place of silica, over any part of the section, without as a rule disturbing its form (fig. 2, *c, e, f*).

A want of symmetry is not uncommon in the sections.   The upper and lower margins of the lobes may be unequally curved, and then it usually happens that the arc of greater curvature lies on the upper side of one lobe and on the lower side of the other. When the inequality is very marked the granular quartz extends into each lobe along opposite margins (fig. 2, *c*).   A bifurcation of the lobes is sometimes to be observed as shown in fig. 2, *e*.   A still more extreme case is represented in fig. 3.

Fig. 3.

Transverse section, showing bifurcation of the lateral lobes (× 60).

The form presented by the transverse sections is probably not original.   The threads have been squeezed flat in the planes of cleavage ; and to discover the primitive form we should seek for the transverse section of a thread running across the cleavage planes. I have not, however, found completely satisfactory evidence of such sections.   Those which seemed to be transverse were oval in outline, with a granular centre and fibrous margins, the fibres running parallel to the long axis, and being most abundant about its extremity.   There is just a possibility that these are disjointed fragments of longitudinal sections ; if they re not but are actually

tranverse, then the original form of the threads may have been cylindrical. It is remarkable in this connection that transverse sections of the slate rarely present any other than truly transverse sections of the threads. In no single instance, though many slices were cut, has a thread been observed running directly transverse to the cleavage, a fact which rather tends to diminish the probability that the oval forms, seen in tangential sections of the slate, are truly transverse sections of the threads.

The longitudinal sections (figs. 4, 5, 6) present a median band of granular quartz, bounded on each side by a band of fibrous quartz, and though the boundary between the lateral and median regions is well defined, it is often possible to trace several marginal fibres into a common origin in one of the central

FIG. 4.

Longitudinal section (× 6). The black spots represent iron pyrites.
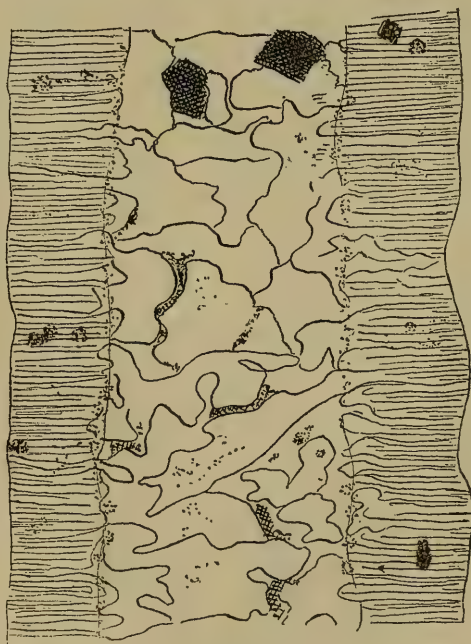
FIG. 5.

Longitudinal section (× 60).

granules (fig. 5). The outer boundary is sharply marked—fairly even or faintly crenate, swelling out into rounded protuberances

suggestive of mammillary chalcedonic growth. In some instances the whole section is transversely constricted at irregular intervals as though segmented. The length of the segment shown in the figure (fig. 6) is 5 mm.

Combining the information we have obtained, it is clear that the form of our fossil is at present that of a flattened band with much thickened margins, but whether this is original or not is by no means certain. Quite possibly the pristine shape was cylindrical, and in that case the fossil may merely represent a cylindrical cavity which has been filled up with silica and deformed by pressure or perhaps a corroded and subsequently silicified sponge spicule like those of the glass rope sponge Hyalonema. The shape of the tranverse sections, however, is difficult to account for on such supposition. A cylindrical tube under the pressure which gave rise to cleavage in the slate would be converted into a flat band of elliptical section, and would not be lemniscate as in our examples. On the other hand it may be the silicified remains of some organism such as an Annelid or perhaps of a plant. Its appearance, however, is more worm than plant-like, and I would hazard the conjecture that it may be another trace

FIG. 6.
Longitudinal section showing constrictions (× 10).

of the same organism that produced the markings known as Oldhamia. The dimensions are consistent with such a view; both are probably worm-markings; both occur in the same rocks in the same locality. The new fossil requires an independent name, and I propose to call it *Pucksia MacHenryi.* "Pucksia" is a mere collocation of letters recalling the place of occurrence. The specific name is a tribute to my colleague, Mr. MacHenry, of the Geological Survey.

The slate in which Pucksia occurs is found on microscopic examination to consist almost entirely of scales of white mica, lying of course with their flat faces parallel to the planes of cleavage.

A chemical analysis of the slate yielded the results given in column I. Its composition approaches very closely that of a phyllite analysed for Gumbel by Schwäger (Roth. Chemische

Geologie, Bd. ii., p. 443). His results are shown in column II. As might naturally be expected in the case of a rock so largely made up of mica, the composition of the slate does not differ greatly from that of the constituent mica, as will be seen by reference to the column III., which gives the composition of a muscovite mica also analysed by Schwäger (Hintze, Handbuch der Mineralogie, p. 631).

	I.	II.	III.
SiO_2, ...	53·954 . .	52·04 . .	55·51 [1]
Al_2O_3, Fe_2O_3, .	33·897 . .	35·77 [2] . .	30·04
CaO, ...	·671 . .	·78 . .	·52
MgO, ...	1·035 . .	2·15 . .	·83
K_2O, ...	3·907 . .	4·36 . .	4·41
Na_2O, ...	3·614 . .	1·61 . .	4·00
H_2O, ...	3·732 [3] . .	3·31 . .	4·31
P_2O_5, ...	·140 . .	— . .	—
	100·950	100·02	99·62

[1] Including 1·51 per cent. of TiO_2.
[2] Including a small quantity of FeO.
[3] Determined by loss on ignition.

XXXIX.

A COLLECTION OF LEPIDOPTERA FROM LOKOJA, WEST
AFRICA. By GEORGE H. CARPENTER, B.Sc., Assistant
Naturalist, Science and Art Museum, Dublin.

WHILE stationed on duty at Lokoja, at the junction of the River
Benue with the Niger, Captain C. W. Soden gathered a small
collection of Lepidoptera, a set of which were secured by the
Dublin Museum. As this district is less known zoologically than
many other parts of West Africa, it seems worth while to publish
a list of the species, especially as the collection includes an un-
described variety of *Euphœdra cyparissa*, Cram., and new species
of *Xanthopsilopteryx*, and of *Antheua*.

I would acknowledge kind help from Messrs. Butler, Kirby,
Hampson, and Heron, when comparing some of these insects with
the British Museum Collection.

The figure after each species indicates the number of specimens.

RHOPALOCERA.

NYMPHALIDÆ.

EUPLŒINÆ.

Tirumala petiverana, Dbl. and Hew. (1).—An African species.
Limnas alcippus, Cram. (9).—A wide-ranging species, Australia to
West Africa.
Amauris niavius, L. (3).—A West African butterfly.

ACRÆINÆ.

Acrœa neobule, Dbl. and Hew. (4).—An interesting species,
recorded from Abyssinia and the Congo, with its nearest
relations in Madagascar.

A. lycia, Fb. (1). ⎫
A. cæcilia, Fb. (2). ⎬ All these species have a wide range over the
A. zetes, L. (9). ⎬   African continent.
A. serena, Fb. (4). ⎭
A. camæna, Dru. (1).—West African species.
A. lycoa, God. (1).   ,,   ,,

NYMPHALINÆ.

Atella eurytis, Dbl. and Hew. (10). ⎫
Junonia clelia, Cram. (8). ⎬ Species with a wide range in
J. crebrene, Trim. (3) ⎭   Africa.
J. orithya, L. (2).—A species occurring in India as well as in
     Africa.
Precis terea, Dru. (1).—West African species.
P. chorimene, Guer. (4).   ,,   ,,
P. Galami, Bdv. (6).   ,,   ,,
Hypanus ilithyia, Dru. (6).—Indian and African.
Hypolimnas misippus, L. (6).—Australia to West Africa.
            ♀ var. *inaria,* Cram. (2).—Australia to West Africa.
Neptis agatha, Cram. (4).—African species.
Euryphene phranza, Hew. (1).—West African species.
Euphædra ceres, Fab. (1).   ,,   ,,
E. Crockeri, Butl. (1).   ,,   ,,
E. cyparissa, var. *aurata,* nov. (8).
     This beautiful variety agrees in form and pattern with the
        type of *cyparissa,* but has the sub-apical spot of the fore-
        wings bright golden instead of dark green; the dark green
        of the under-side of the fore-wings is also largely replaced
        by the golden colour.* This variety resembles *E. sarcoptera,*
        Butl., but has no red beneath the base of the fore-wing.
Hamanumida dædalus, Fab. (5).—African species.
Charaxes epijasius, Reiche (6).—Recorded from Senegal and
     Abyssinia.
C. achæmenes, Feld. (2).—African species.
Palla varanes, Cram. (2).   ,,   ,,

LIBYTHÆIDÆ.

Libythœa labdaca, Westw. (1).—Recorded from Sierra Leone.

LYCÆNIDÆ.

Tarucus plinius, Fab. (1).—This is an Indian species, and I am not aware that it has been yet recorded as occurring in Africa.

T. pulcher, Murr. (1).—A West African species.

Virachola anta, Trim. (1).—This species is recorded only from South Africa. Its presence on the Niger shows it to have a wide range over the continent.

Sithon nomenia, Hew. (1).—A West African species.

Myrina hymen, Fab. (1).   ,,   ,,

PAPILIONIDÆ.

PIERINÆ.

Eurema senegalensis, Bdv. (2).—A West African species.

E. regularis, Btl. (2).

E. zoe, Hopff. (1).

These species are described from East Africa. They must therefore have a wide range over the Continent. There are specimens of the latter from Natal in the British Museum Collection.

Pieris creona, Cram. (2).
P. calypso, Dru. (6).
Tachyris saba, Fb. (4).
T. sylvia, Fb. (4).
} All species with a wide range in Africa.

Eronia poppea, Don. (1).—A West African species.

Catopsilia pyrene, Swains. (2).—African species.

Callosune evippe, L. (2).—A West African species.

C. arethusa, Dru.   ,,   ,,

C. ocale, Bdv.   ,,   ,,

PAPILIONINÆ.

Papilio ridleyanus, White (1).—Recorded from the Congo.

P. leonidas, Fb. (10).
P. demoleus, L. (18).
P. policenes, Cram. (3). All these species have a wide range in
P. pylades, Fb. (14). Africa.
P. nireus, L. (1).
P. erinus, Gray (2).

HESPERIIDÆ.

Celænorrhinus galenus, Fb. (1).—A West African species.

HETEROCERA.

SATURNIIDÆ.

Gonimbrasia nictitans, Fb. (2).—A West African species.

SPHINGIDÆ.

Chœrocampa gracilis, Butl. (2).—A West African species.
Pergesa irregularis, Wlk. (1). ,, ,,
Diodosida fumosa, Wlk. (1). ,, ,,
Nephele variegata, Butl. (2).—Recorded from the Congo.
N. funebris, Fb. (1). ,, ,,

NOTODONTIDÆ.

Antheua nigrolineata, sp. nov. (1).—Male (fig. 1). Expanse of
wings, 37 mm. Head and thorax grey. Antennæ yellow.
Abdomen yellow above, basal segment white; white beneath; spotted with black along the sides. Wings white; fore-wing with pale yellow costa, a strong black streak along the median vein for three-fourths the length of the wing, and a few scattered black scales.

FIG. 1.
Antheua nigrolineata.

This is a very distinct species. Its nearest ally appears to be *A. spurcata,* Wlk., from Sierra Leone, which is larger, has a yellow streak on the fore-wing, and a differently-marked abdomen.

AGARISTIDÆ.

Ægocera Boisduvalii, Latr. (1).—A West African species.
Æ. rectilinea, Bdv. (3).   ,,   ,,

Xanthopsilopteryx Kirbyi, sp. nov. (1).—Male (fig. 2). Expanse
    of wings, 65 mm. Head and thorax black. Head with two
    white spots before, and two behind antennæ; thorax with a
    row of four white spots in front,
    and three across centre. Abdo-
    men yellow, banded with black,
    and a large black anal tuft. Fore-
    wings black; near the base a row
    of four small white spots below
    the costa, and three yellow spots.
    Beyond these, two yellow spots;
    one near the costa, semicircular,
    convex towards the base, *one*

Fɪɢ. 2.
Xanthopsilopteryx Kirbyi.

touching the inner margin, triangular. Beyond these, a row of
three yellow spots; one near the costa, semicircular, convex
towards the apex, the central larger and quadrate, the third
near (but not touching) the anal angle, small and triangular.
Beyond these, a large subapical transverse yellow spot of
flattened elliptical shape. Tip of wings white. Hind-wings
brilliant orange, with black border, narrowest at anal angle,
broadening and then narrowing again along hind margin,
broadest at apex, which is tipped with white.

    The species of this brilliant genus are very similar in
general aspect, but the markings appear to be very constant,
and thanks to the British Museum Collection, and Mr. W.
F. Kirby's Monograph of the group (*Trans. Ent. Soc.*, 1891),
the present species (which I have much pleasure in dedicating
to that naturalist) could be separated from its allies. It is
nearly related to *X. superba*, Butl., but the size is smaller,
the fore-wings proportionally much narrower, and the sub-
apical spot smaller and narrower. From *X. eva*, Mab., *X.
indecisa*, Wlk., and *X. africana*, Butl., it may be separated by
its inner yellow band broken into two spots, those species
having the band entire. In *X. xanthopyga*, Mab., the second

band (in our species broken into three spots) is entire. Its nearest relation is, perhaps, *X. fatima*, Kirb., an East African species, but in that the second yellow spot of the first row does not extend along the inner margin, while the sub-apical spot is irregular in form.

NOCTUIDÆ.

Cyligramma latona, Cram. (5).—South and West African species.

C. fluctuosa, Dru. (2).—West African species.

Hypocala Moorei, Butl. (2).—This species was first found in India and Ceylon, but is known to occur as well in West Africa.

Ophiusa algira, L. (1).—A very wide-ranging species, from South Europe to the Cape and to Burmah.

Achæa catocaloides, Guen. (1).—A West African species.

A. ezea, Cram. (2).   ,,   ,,

A. chameleon, Guen. (1).—A variable species with a wide range in Africa. This specimen has the wings almost unicolorous.

Entomogramma nigriceps, Wlk. (1).—A West African species.

Othreis fullonica, L. (1).

O. materna, L. (1).

These two species have both a very wide range, the former ranging from West Africa through India and Malaya to Australia, the latter as far as Java. I am not aware that *O. materna* has been previously recorded from Africa.

ARCTIIDÆ.

Tæniopyga evidens, Guér. (1).—Recorded from Senegal.

LITHOSIIDÆ.

Argina cingulifera, Wlk. (1).—Recorded from the Congo.

Deiopeia pulchella, L. (1).—This species ranges over the whole of the warm and temperate parts of the Eastern Hemisphere.

PYRALIDÆ.

Margaronia sericea, Dru. (1).—A West African species.

ZYGÆNIDÆ.

Euchromia fulvida, Butl. (2.)—A West African species.

Of the eighty forms comprised in the above list, sixty-nine are, so far as is known, peculiar to the Ethiopian region, and thirty-nine of these have hitherto been found only in West Africa. Five of the remaining eleven are common to the Ethiopian and Oriental regions, one to those two regions and also to the Palæarctic, four to the Ethiopian, Oriental, and Australian regions, and one to all the regions of the Old World. It will be noticed, therefore, that about fifteen per cent. of the species are not peculiar to the region in which they were found. This is an indication of the fact that there is less speciality in the lepidopterous than in the vertebrate fauna of each great zoological division of the earth's surface. The relationship between the Ethiopian and Oriental faunas, shown in this small collection by the specific identity of such a fair number of insects with Indian forms, would, in a collection of vertebrates, be indicated hardly at all by identical species, but only by common genera or families.

XL.

ON THE GOLD NUGGETS HITHERTO FOUND IN THE
COUNTY WICKLOW. By V. BALL, C.B., LL.D., F.R.S.
(Plate XIII.)

In the Science and Art Museum there are two lead models, belong-
ing respectively to the original Royal Irish Academy and the
Royal Dublin Society Collections, of a large gold nugget which
was found in Wicklow in 1795, and weighed, as we shall see,
about 22 o̅z. Being anxious to provide a proper descriptive label
for these models, I commenced, some time ago, an investiga-
tion of the various historical facts and of the supplemental tra-
ditions and myths (for such they have proved to be) regarding
the discovery and the disposal of the original nugget, and I
now propose to record the results of these researches.

The actual discovery of the nugget took place, it is believed,
in or before September, 1795; and tradition asserts that on the
occasion of the visit of George IV. to Ireland, in 1821, it was either
presented to his Majesty at the instigation of an "officious mem-
ber" of the Dublin Society, or, when merely intended to be shown,
was claimed by the king as a *droit*, placed in his pocket, and
never seen or heard of again by the Society, having been given,
so it is said, to a lady, who caused it to be melted down. This, in
brief, is the story which has been tacitly accepted by all who have
written about the nugget for the last thirty or forty years. So
far as is known it was first actually published so recently as
the year 1865,[1] but according to a letter received last September
from the late Mr. Gilbert Sanders, it seems to have been current
at an earlier date. And, as we shall see, there is said to have
been a claimant for the authorship of the fable in the year 1833.

---

[1] Journ. Geol. Soc., Ireland, vol. xi., 1865, p. 100.

Like all such stories, and I have had to deal with many in my researches regarding Indian myths, the number of variants of the details is in the inverse ratio to the number of authentic facts.

The majority[1] of these variants concur in the statement that the incident above referred to took place when his Majesty visited Leinster House on Friday, the 21st August, 1821. But of that visit there is a printed account[2]; and although it is a record of the transactions which took place on the occasion, there is not the least reference in it to a gold nugget, and the Registrar of the Royal Dublin Society informs me that he has not been able to trace any allusion to it in the MS. records of the Society, and it is certainly not mentioned in the printed "Proceedings."

If the story be true, the nugget must have been the property of the Dublin Society, or have been deposited in its care at the time. It is not, however, included in any of the early Catalogues of the Society's Minerals and other possessions, which still exist. On the contrary, that of 1832 affords internal, if indirect, evidence that Sir Charles Giesecke, who was in charge of the minerals from 1813 to 1832, had himself never seen the nugget, for, in his supplementary remarks on Irish minerals, Catalogue, p. 241, he merely says that the largest mass of gold ever found in Wicklow weighed about 25 oz., and that a model of it was in the Museum. Here there is no mention of the history of the nugget, while the ascription to it of the weight 25 oz. is apparently incorrect.

Besides the two models above referred to, there are at least two others, one in the Geological Museum of Trinity College, which is the only one with an original (?) label, as follows :— "Moddel of a piece of gold found at Croughan." This is in an old-looking handwriting, and, as will be noticed, in an obsolete orthography. The fourth belongs to Dr. Fraser, who obtained it from Mr. Glennon. In a letter from Mrs. Baker, daughter of the latter, which Dr. Fraser has placed in my hands, it is stated that the model was cast by her father for a gentleman who

---

[1] One version of the story, however, is that the nugget was presented to George IV. on the occasion of his visit to Powerscourt, but Lord Powerscourt informs me there is no foundation for it. Another version connects the donation with the Earl of Meath, as we shall see.

[2] "The Royal Visit," &c. Dublin : Crookes, 8vo, 1821.

presented the original to the Dublin Society. This I cannot, under the above-mentioned circumstances, accept as authentic. I think it more probable that Dr. Fraser's model came into Mr. Glennon's hands from some predecessor of his, or was perhaps purchased by him at a sale, or it may have been merely a copy of the Dublin Society's model.

Having ascertained that there were no copies of this model in the museums of London or Edinburgh, I have supplied the deficiency from some plaster casts which have recently been prepared.

If the history about to be presented is, as I believe it to be, the true one, then the original mould from which the models were cast was probably prepared about the end of the year 1795 or the beginning of 1796, and the best chance of finding any record of the fact would probably be in the press or magazines of that period, which have as yet only been partially examined for that purpose.

The Dublin Society's model is the best and sharpest of the four, and was probably the first taken from the mould, which became injured by successive lead castings, as is commonly the case.

Before completing the history which follows, I made inquiries through Mr. Richard Holmes, Librarian at Windsor Castle, as to the possibility of the nugget being still in existence, and as to there being anything on record regarding it, but I have been informed by him that so far he has been unable to trace it.

With reference to the origin of the story connecting this nugget with George IV., it may be suggested that a gold nugget received, as we shall see, from the Government in 1800, which at the time of his visit was in the collection of the Royal Dublin Society, and is now in the Science and Art Museum, may have been shown to his Majesty as being an object of special interest. It weighs 1502·5 grs., *vide post*, p. 321, and Pl. XIII., fig. 3); but, if so, as it is here still, the statement made in some of the stories that the king thereupon put the nugget into his pocket is thereby disproved. As regards the large nugget which weighed nearly 2 lbs. it is ridiculous to suggest that his Majesty could have so far forgotten his dignity as to have done so, and it is in itself sufficient to discredit the whole myth. There is no evidence, it may be added, of any other nugget having been in the possession of the

Dublin Society at the time, which might have been given to the king instead of either of the above.

One informant assures me that Mr. Patrick Brophy, State Dentist, claimed to have been the inventor and retailer of the story about George IV., and professed to have amused the Marquis of Wellesley with it at a dinner party during his second Viceroyalty in 1833.

Dr. Fraser has suggested that a Mossop medal, made of Irish silver, which was certainly presented to the king, was possibly the origin of the story. This may have been the foundation. Or there may be some truth in the story that a nugget was given to the king by the Earl of Meath, as I am informed by the present Earl that there is a tradition to that effect in his family.

Discovery of the 22 oz. Nugget (see Pl. XIII., fig. 4).—In letters written by John Lloyd, F.R.S.[1] and Abraham Mills[2] to Sir Joseph Banks, President of the Royal Society, they describe respectively the results of their visit, in company with Mr. Weaver, to the scene of the Wicklow gold washings. Mr. Weaver's own account was not published till many years later.

I do not propose to deal here with all the traditional stories as to the discovery of nuggets, and the annual search for gold which appears to have been carried on by certain families who shared the secret for at least ten or twelve years before the year 1795.

The discovery of the washings at Croghan Kinshela was first made public in September of that year. The rush took place soon afterwards, and the working by the peasantry continued till the 15th October, when, under orders of the Government, a detachment of the Kildare Militia took possession of the washings for the Crown, and the peasantry retired quietly. According to Mills the latter had, during the six weeks, disposed of £3000 worth of gold at about £3 15s. per oz. = 800 ozs.

It is not clear from the above authors alone whether the 22 oz. nugget which was first referred to by Lloyd was found

---

[1] Dated Cronbane, 4th November, 1795. Read 19th November, 1795. Phil. Trans., vol. lxxxvi., 1796, pp. 34–37.

[2] Dated Cronbane, 21st November, 1795. Read 17th December, 1795. Phil. Trans., vol. lxxxvi., 1796, pp. 38, 44. See also Trans. Roy. Dub. Society for 1800, vol. ii., Pt. i., p. 454.

by the peasantry before the 15th October, or by the Government between that date and the 3rd–4th November when his letter was written.

As affording some clue to the discovery and original owner-ship, an account of it in the *Gentleman's Magazine*,[1] however, states that it was found in September, 1795, and was the joint pro-perty of eight labourers.

It can scarcely therefore be identified with a nugget which was said to have long been used as a weight in a shop, in the belief that it was copper ore, till it was bought by a tinker and sold to a jeweller in Capel-street for a large sum. Of this tale there are several variants.[2] The following account by Mr. W. H. Jones, has been received through Mr. G. H. Kinahan :—

" I know of no record of the quantity of gold found unless that given in ' Lewis' Topographical Dictionary.' I always heard of a large nugget being found by a tenant of Mr. Wm. Graham, of Ballycooge. It was used by the finder as a weight to weigh wool, until a pedlar called and offered a high price for it. The man began to think it valuable, and declined to part with it, but brought it to Mr. W. Graham, his landlord, and gave it to him. Mr. Graham presented it to Lord Meath, and Lord Meath presented it to the Dublin Society Museum, where there is a model of it, I understand, at present. I never heard of a nugget being found at Coolballintegart. The Graham family have all died out, and I am quite certain that they left no written record ; they were not people likely to keep a diary ; indeed, according to report, poor Shemus McGlinnon, who found the nugget, got little by it."

At a meeting of the Royal Geological Society of Ireland held on the 11th January, 1865, Mr. J. Knight Boswell stated that he was told by a family named Byrne, farmers at Croghan Kinshela, some thirty years previously, that in the upper part of one of the rivers they found a mass of metal, about a pound and a-half in weight, which they supposed to be copper. It remained for several years in their possession, and was used by them as a weight ; but at length it was disposed of to a travelling tinker who carried it to

---

[1] Vol. 66, pt. i., 1796, p. 8.
[2] Journ. Roy. Geol. Soc., Ireland, vol. xi. (New Ser., vol. i., Pt. i.), 1865, p. 99.

Dublin, where he sold it for a large price to a jeweller in Capel-street. That was what led to the Government investigations there in 1796. [1]

This appears to be due to a blending by the family of the story of the discovery, about 1784 or 1785, by John Byrne, of a nugget of a quarter of an ounce,[2] with that of the 22 oz. nugget which was certainly not sold to a tinker as we shall presently see.

Lloyd says (p. 36) that it was intended to present the 22 oz. nugget to his Majesty George III., for which purpose it may be supposed that the Government acquired it. Gerrard Kinahan[3] includes it and two others, mentioned by Mills, of 5 oz. and 2 oz. 17 dwt., and one of 20 oz. 2 dwt. 21 grs. mentioned by Molesworth in his table as having been *found* by the peasants. I am quite satisfied that the nugget weighed by Molesworth,[4] though his language is obscure, was the same 22 oz. one, and that the weight he gives was either its weight in water, or the weight of pure gold in the nugget, and that it should not be regarded as re-ferring to a separate nugget as Kinahan suggests. Molesworth found its specific gravity to be to that of pure gold as 12 to 18 ; and Kirwan found that of another specimen to be as 13 to 18.

The *Hibernian Magazine*[5] gives a somewhat exaggerated account of the value of the mine. It refers to a nugget that was in the possession of Mr. Atkinson, agent to Lord Carysfort, for which eighty guineas was offered, but was refused. The story also is related of a yarn-dealer who, for ten years, had used a piece of " gold ore " as a two-pound weight, believing it to be copper ore, and had broken several pieces from it to adjust the weight. It had then recently been sold for a considerable sum.

Most of the early writers whom we have quoted from in this Paper simply attribute a weight of 22 oz. to the nugget, namely, Lloyd, Mills, and Kirwan,[6] in 1795–6 ; and, among later writers, Mallet in 1849, and Gilbert Sanders and R. Scott in 1865.

---

[1] Journal of the Royal Geol. Soc., vol. xi., 1865, p. 99.

[2] See Phil. Trans., vol. lxxxvi., 1796, pp. 34–37.

[3] " On the occurrence and winning of gold in Ireland," Journ. Roy. Geol. Soc., Ireland, vol. vi. (New Ser., Pt. ii.), 1882, p. 147.

[4] Phil. Trans. 1796, vol. lxxxvi., pp. 44, 45.

[5] Part ii., 1795, p. 382.

[6] Mineralogy, vol. ii., p. 93 n.

Apjohn,[1] upon what authority is not stated, gives the weight at 22·7 oz., and " B. D." says 22 oz. avoirdupois ! which seems a curious measure for gold. It would be equal to 26 oz. 18 dwt. troy, but then it is inconsistent with the further statement that the nugget was sold for £80 12s., or at the rate of £4 per oz. ; for in that case the weight would only have been 20 oz. 6 dwt. troy.

Finally, Sir Charles Giesecke said it weighed 25 oz., which, combined with the absence of further information, convinces me that he never saw the nugget, that it had in fact left Ireland before he arrived in 1813.

Subsequent History.—From the letter signed " B. D." to the editor of the *Gentleman's Magazine*,[2] which has already been quoted, the purchase of the nugget appears to have been made by Turner Camac who paid for it, it is said, £801 2s.[3] Turner Camac, as one of the partners of the Hibernian Mining Company, was a well-known personage. This Company issued tokens which were popularly known as Camacs ; several varieties were issued during the years 1792, 1796.

The record just referred to goes on to say that the nugget was then, January, 1796, already believed to be " in the possession of his Majesty " (George III.), but we are left in doubt as to the person or persons by whom the project of presenting it to him, originally mentioned in November, 1795, by Lloyd,[4] had actually been carried out.

A clue has been found, however, in rather a curious way. I am informed by Dr. W. J. Fitzpatrick, to whom I referred the question, with reference to the George IV. story, that he had casually become aware of the fact that a gold nugget had been presented to George III. by a gentleman named Abraham Coates, and that the discovery was made as follows :—In the papers of Mr. Kemmis, Crown and Treasury Solicitor, a payment of £300 was ordered in the year 1803 to be made to Abraham Coates of Arklow. Noticing this, Dr. Fitzpatrick instituted inquiries in 1883 as to what was known regarding Abraham Coates, by his

---

[1] Catalogue of Minerals in Museum of Trinity College, Dublin.

[2] Vol. 66, Pt. i., 1796, p. 8.

[3] See also *Penny Magazine*, vol. xiii., 1844, pp. 426–7.

[4] See his letter in Phil. Trans., vol. lxxxvi., 1796, p. 36.

descendants, with the result that he then made the following memorandum which he has now placed at my disposal :—

" I learn from the Coates family that Abraham found, in one of the Wicklow mines, a nugget of gold which he sent to George III. The King, much interested, got the ore made into a snuffbox, and signified to Lord Brabazon, as M. P. for Wicklow, that it would gratify him to hear of Mr. Coates being appointed to some lucrative post in the county. Soon afterwards Mr. Coates received the office of Coast Surveyor. It was his business to keep a sharp eye on all ships touching the Wicklow coast. Coates was a J.P., and there is a street in Wicklow called after his name."

My attention being thus called to Abraham Coates, I at once remembered that he was one of those who accompanied the troops to take possession of the mines, as is mentioned in the following rather sarcastic remarks from the *Gentleman's Magazine* dated Dublin, October 20 :—" The mines at little Peru (otherwise Croghan Mountain) were taken possession of on behalf of his Majesty. Major Brown of the Royal Engineers, attended by Mr. Coates, Port Surveyor of Wicklow, marched two companies of the Kildare Militia from the Barracks of Arklow towards the place where the gold is got; but, with great judgment and propriety, on consulting with that active and spirited magistrate, Thomas King, Esq., it was judged proper to send a constable before them to read a proclamation, and advise the crowd to disperse and leave the ground. In an hour afterwards, the Major, accompanied by Mr. King, Mr. Hayes, Sub-Sheriff (who readily attended), and Mr. Coates, marched the army (about sixty-eight men rank and file) to the place, when the crowd immediately, without riot or resistance, dispersed.

" When men who conduct themselves with such coolness, judgment, and spirit, as these gentlemen did, support the Laws, there is no danger of opposition. It is much to the credit of the peasantry of the county of Wicklow that not the slightest opposition had been given to the execution of the Law; that county is not cursed with disloyal defenders."[1]

Whatever promotion Abraham Coates may have received, as stated by his family, at the instance of the King and on account

---

[1] *Gentleman's Magazine*, October, 1795, vol. 65, Pt. ii., p. 870.

of his presentation of a nugget to his Majesty, he is by the above brought into touch, so to speak, with the 22 oz. nugget, and as he was styled Port Surveyor then, the change may have been to that of Coast Surveyor, as he is called in Dr. Fitzpatrick's Memorandum.

I am not prepared at present to follow up this identification of the donor and recipient of the 22 oz. nugget any further, but I think we are justified in the conclusion that Abraham Coates and Turner Camac were probably the donors, or, at least, were connected with the donation, and that George III. was the recipient.

Although I have not been able to obtain information from Windsor Castle as to the existence of any trace of this transaction, I by no means despair of such being ultimately found. That a snuff-box was made of a 22 oz. nugget may seem incredible, but possibly in some other form, and with an inscription, the metal may have been preserved, and this record of fact and dissipation of myth will, I trust, aid in its ultimate identification.

It may not be generally known that the discovery of the mines led to a dramatic performance being enacted at Covent Garden, under the title:—" The Lad o' the Hills; or, the Wicklow Gold Mines: " a Comic Opera, by Mr. O'Keeffe.[1]

Having thus placed the history of one of the largest Wicklow nuggets in a clearer position than it has hitherto occupied, and brushed away some of the myths and traditions which have for so many years obscured it, let us proceed to discuss the histories of the principal remaining Wicklow nuggets known to fame.

I studiously avoid discussing the question of the character and production generally of the Wicklow Mines themselves; that has already been well done by the late Mr. Gerrard Kinahan. Probably he had neither the means nor the opportunities for conducting a critical investigation into the histories of the individual nuggets; this has rendered it desirable that they should be discussed fully and at length; and it must be added that his table giving the weights and other particulars of the nuggets found, requires considerable amendment in the light of the facts here collected and placed in order.

Nugget of 5 ounces.—John Lloyd in his letter to Sir Joseph

---

[1] See *Hibernian Magazine*, Pt. i., 1795, p. 461.

Banks, dated 4th November, 1795,[1] besides mentioning the nugget of 22 oz., which it was intended to present to his Majesty, refers to one of 5 oz. which was destined " for the cabinet of a nobleman adored in this country." Whether Earl Camden, the then Lord Lieutenant, was indicated by this reference I cannot say. Possibly it may have been the Earl of Meath.

If the weight of this nugget was really 5 oz., then it cannot be identified with any of those of lesser weight which are described in the following pages. It may have been the one said to have been given to George IV. by the Earl of Meath as we have seen.

According to Mills it and the 22 oz. were the only two of *superior* weight which had then been found.

Weaver,[2] at a later period (1819) speaks of nuggets of 18 oz., 9 oz., and 7 oz., in addition to that of 22 oz., but of these we have no other record.

And here we may conveniently refer, too, to one of 24 oz. (valued at £100), and another of 6 oz. (valued at £30), which are said to have been found by the peasants in 1856. The authority quoted by Gerrard Kinahan[3] is Mr. Hugh M'Dermott of Arklow, but nothing further seems to be recorded regarding them.

Nugget of 2112 *grs.* = 4 *oz.* 8 *dwt.*—In the year 1844 the Mining Company of Ireland exhibited at their stall in the Royal Dublin Society's Exhibition,[4] together with a cake of silver of $893\frac{1}{2}$ oz., obtained from lead, a nugget of gold of about 4 oz. I have not been able to refer to the original catalogue of this Exhibition as yet; two of the daily papers [5] of the time, however, attest the fact, but the " Evening Mail "[6] by a misprint gave the weight as 40 oz. ! and this probably was the source from whence the " Mining Journal "[7] quoted the latter weight. Hence originated the supposed champion nugget of the United Kingdom, which

[1] Phil. Trans., vol. lxxxvi., 1796, p. 362, *loc. cit.*, p. 44.

[2] Trans. Geol. Soc., vol. v., 1819, pp. 115–304 ; and Phil. Mag. vii., 1835, p. 3.

[3] Journ. Roy. Geol. Soc., Ireland, vol. xvi., Pt. ii., 1882, pp. 146 n., 147.

[4] See Proceedings Royal Dublin Society, vol. lxxx., p. 214.

[5] *Saunders and Evening Post* of June, 1844.

[6] *Dublin Evening Mail*, 7th June, 1844.

[7] *Mining Journal*, 1844, vol. xiv., p. 199.

Calvert[1] points out exceeded in weight the Crawford nugget of 30 oz., said to have been found in the 16th century. Thus our champion proves to be a myth.

This nugget of 2112 grs. was subsequently obtained by Sir Robert Kane from Mr. R. Purdon, Secretary to the Mining Company of Ireland; and I am informed by Dr. Fraser that in the year 1862 he saw it on exhibition in the Museum of Irish Industry. In the year 1865, together with some other specimens, including ancient Irish ornaments of gold, it was stolen from the Museum, and was, in all probability, promptly consigned to the melting pot; so that we are not likely to see it again.

Nugget of 1502·5 *grs.*=3 *oz.* 2 *dwt.* 14·5 *grs.* (see Pl. XIII. fig. 3).— Formerly the weight of this nugget was stated to be 1507 grs.,[2] and the specimen is still so marked on the label. The difference is probably due to the removal of a sample, say 4·5 grs. for assay.

Appended to a reprint of the paper by Mills in the Phil. Trans., which has been referred to above, p. 314, the Transactions of the Royal Dublin Society for 1800[3] contain some notes, including the following :—" By command of our Noble President, Earl Hardwicke, Lord Lieutenant, the Museum of the Society has been furnished with a lump of gold weighing 3 ounces, and 1 ounce of small scales from these mines; the lump is of a prismatical form; on two sides are several grains of white quartz, sunk in the metal; on several of the small scales the quartz is also discoverable."—*G. Vallancy.*

Although this description hardly conveys a proper conception of the amount of quartz present in the nugget, which really permeates the mass, it cannot but refer to the very specimen under description, and of which the figure conveys a good idea. The scales, so called, are still in the Collection.

The very true remark has before now been made with regard to the Wicklow gold, that although as yet it has not been found in quartz (*i.e. in situ*), quartz is often found in the gold.

---

[1] " Gold Rocks of Great Britain and Ireland," London, 1853, p. 174. Mr. G. Kinahan seems to have been misled by this authority when referring to the 40 oz. nugget. See Journ. Roy. Geol. Society, vol. vi., Pt. ii., 1882, p. 140, note.

[2] In Giesecke's Catalogue, 1832, p. 241. It is referred to however as weighing oz. and as 1500 grs. in Journ. Roy. Geol. Soc., vol. xi., 1865, p. 99.

[3] Dublin, vol. ii. 1801, p. 465.

Nugget of 1332 *grs.*=2 oz. 15 *dwt.* 12 *grs.* (see Pl. xiii. fig. 2).—
Recently I have been shown by Mr. E. Johnson a Wicklow nugget
which belonged to his father. Its weight is as above, and the
form is somewhat peculiar, having a flattened wedge-like shape,
somewhat resembling that of a razor, and reproducing no doubt
the outlines of the cleft in the quartz wherein it was formed.

This nugget has long been in the possession of Mr. Johnson's
family, and it may perhaps be identical with the one of 2 oz.
17 dwt.[1] mentioned by Mills ;[2] but, so far as I am aware, there is
nothing known more than an approximate correspondence in
weight to connect them. Its value at present is said to be
£11 5s. [Since the above was written, it has been purchased
for the Museum.]

Nugget of 815·2 grs. (formerly in Trinity College Museum).—
This specimen is described in Apjohn's Catalogue of Minerals,
No. 1973, as being penetrated by several cavities and weighing
as above. It was found at Croghan Kinshela.

Nugget of 336 grs. (see Pl. xiii., fig. 1).—This nugget belongs
to Mr. T. H. Longfield, by whom it was purchased, being at the
time labelled as being from Wicklow. From its general aspect
and similarity to other specimens that was probably its place
of origin. Its form will be seen from the figure. It might be com-
pared both in shape and size to a quarter of the kernel of a
good-sized walnut.

Nugget of 320 grs.—Mr. Gilbert Sanders,[3] in some interesting
remarks on the Wicklow gold fields, with the working of which,
by the Carysfort Mining Company, he was associated, states that
the largest nugget which had come under his personal notice only
weighed 320 grs.

Nugget of 180·8 grs.—This specimen is described in Apjohn's
Catalogue of Minerals (Trinity College Museum), No. 1974, as
being an irregular wrinkled mass of the above weight. It was

---

[1] This weight was misquoted in the *Gentleman's Magazine*, vol. 66, Pt. ii.,
1796, p. 1020, as though it were 21 oz. 17 dwt., so causing some confusion.

[2] Phil. Trans., vol. lxxxvi., p. 44.

[3] Journ. Roy. Geol. Society of Ireland, vol. xi., 1865, p. 101 ; and vol. xvi., 1882,
p. 146.

found at Croghan Kinshela, and appears to be identical with the one mentioned in the 1818 Catalogue under No. 816.

In the Edinburgh Museum, there are five nuggets of Wicklow gold which there is reason to believe were formerly in the well-known collection of the late Chancellor Brady.

I am informed by Dr. Traquair that they weigh as follows :—

$$\begin{array}{lllll}
\text{i.—6·48} & \text{grams} & = & \text{100·01} & \text{grains.} \\
\text{ii.—3·71} & ,, & = & 57·25 & ,, \\
\text{iii.—3·50} & ,, & = & 54·02 & ,, \\
\text{iv.—2·75} & ,, & = & 42·44 & ,, \\
\text{v.—1·84} & ,, & = & 28·396 & ,, \\
\end{array}$$

Models of these have recently been presented to, and are now exhibited in the Science and Art Museum, Dublin.

In the Museum of Practical Geology in Jermyn-street, there are in all seven nuggets of Wicklow gold, as follows; for the descriptions I am indebted to the Curator, Mr. F. W. Rudler :—

I.—Gold associated with cavernous quartz, not much rolled, 30·749 grams (= 474·53 grains).

II.—Gold associated with pure white quartz and much rolled, 26·377 grams = 407·99 grains.

III.—Gold associated with iron-stained vein quartz, much worn, 15·963 grams = 246·34 grains.

IV. AND V.—Two small irregularly shaped masses.

VI. AND VII.—Two small flattened nuggets.

Models of the first three of these have also been recently presented to the Science and Art Museum, Dublin.

EXPLANATION OF PLATE XIII.

————

WICKLOW GOLD.

1. Nugget weighing 336 grains, the property of Mr. T. H. Longfield, see p. 322.

2. Nugget weighing 1332 grains (2 oz. 15 dwt. 12 grains), now in the Science and Art Museum, see p. 322.

3. Nugget weighing 1502·5 grains (3 oz. 2 dwt. 14·5 grains), now in the Science and Art Museum, see p. 321.

4. Model of nugget weighing 22 oz., believed to have been presented to George III. in the year 1796, see p. 314.

XLI.

SURVEY OF FISHING GROUNDS, WEST COAST OF IRELAND, 1890–91. NOTES ON THE HYDROIDA AND POLYZOA. By J. E. DUERDEN, A.R.C. Sc. (London); Curator of the Museum of the Institute of Jamaica. (PLATE XIV.)

THE following communication consists of notes on only the more important species of Hydroida and Polyzoa, collected by the Survey. A fuller and complete list of the Irish representatives of these two groups of the Zoophytes is in preparation, and it is intended there to record the abundance of more common forms obtained. In the present Paper, the following Hydroids are recorded as new to Ireland :—

Tubiclava cornucopiæ, Norman. *Eudendrium insigne*, Hincks. *Perigonimus gelatinosus*, n. sp. *P. inflatus*, n. sp. *Campanulina panicula*, G. O. Sars. *Bimeria vestita*, T. S. Wright.

The following Polyzoa are also recorded as being collected by the Survey, and new to Ireland :—

Bicellaria Alderi, Busk. *Flustra Barleei*, Busk. *Triticella pedicellata*, Alder.

Campanulina panicula, G. O. Sars, is new to the British seas, being previously known only from Christiania Sound. *Perigonimus gelatinosus* and *P. inflatus* are new to science.

HYDROIDA.

Tubiclava cornucopiæ, Norman.

In the collections obtained from Blacksod Bay I found four shells of *Astarte sulcata*, each with the animal inside, and each bearing at its posterior end a colony of numerous individuals of this interesting species. The zoophyte takes up this posterior

position on the shell, so that it may receive the full benefit of the food-particles which may be in the current set up by the living mollusc, as has been shown by Canon Norman. It is a very rare species, and new to Ireland. It has previously been obtained by Canon Norman from about twenty miles north of Unst, in Scotland, parasitic on the shells of *Astarte sulcata* and *Dentalium entalis*; and by Mr. Alder, from the coast of Northumberland, also on *Dentalium entalis*. The Irish specimens from Blacksod Bay were obtained at a depth of from six to eight fathoms.

Eudendrium insigne, Hincks.

In this minute species the stem is ringed throughout and not much branched. It is now recorded for the first time from Ireland, having been collected by the Survey from Lough Swilly at a depth of from eight to twelve fathoms. It is only known from a few English localities.

Perigonimus repens, T. S. Wright.

A rich supply of different forms of the genus *Perigonimus* has been collected by the Survey. It is a somewhat difficult group to study, especially from spirit material; and it is only by comparison with an abundance of forms that reliable identifications can be obtained. The limitations of the species are not well defined in the size, amount of branching, and the characters of the polypary. Some of the species have certainly been described from too limited a supply of material.

A much branched condition of *P. repens* is represented on Plate xiv., figure 1. There are five distinct branches or bifurcations, one of them bearing a characteristic gonophore. Others, arising from the same colony, were also elongated, but without any branching, exactly as represented in Alder's drawing of the species reproduced by Hincks on pl. 16, "Brit. Hyd. Zooph." The polypary is thin and delicate, but less so proximally. It is covered with a rather thick layer of a gelatinous substance, in which is embedded foreign matter, consisting mostly of fine mud. The stems at their origin have two or three distinct

annulations, and a less amount of the gelatinous and foreign encrusting matter. The gonophores show a distinct delicate continuation of the polypary over them. In the great amount of branching, and also in the ringed origin of the stems, this form varies from the description given of *P. repens*; but these characters I regard as insufficient to establish a specific distinction.

A colony of this form was obtained growing luxuriantly on a *Scaphander* from Galway Bay, from a depth of 15 fathoms, and another colony from off the Skelligs, at a depth of from 40 to 80 fathoms. Collections from Dingle Bay also yielded this more branching form with the stems annulated at their origin.

From Bantry Bay I received a colony of the form resembling the one which Mr. Alder regards as the young stage of *P. repens* ("Brit. Hyd. Zooph.," fol. 17). It was growing upon a crab. The stems are quite short compared with the examples described above. One interesting feature in these is, that within the gastric cavity of many of the polypites a nematode is present. I have found this relationship in quite a number of cases, both in specimens of *Perigonimus* and of *Bougainvillia*. It appears as if the nematode were capable of making its exit, as I have found them projecting some distance beyond the mouth of the polypite, and in other cases quite free amongst the branches. It is evidently a condition of partial parasitism.

Perigonimus gelatinosus, n. sp.

(Pl. XIV., figs. 2 and 3.)

Stems short and simple, or longer, and with a few branches; *polypary* yellowish, gradually thinning above, and greatly expanded to form a thin covering for the polypites; nine or ten distinct annulations at the origin of the stems; somewhat wrinkled; covered on the outside with a gelatinous envelope, developed to a greater or less extent with foreign particles embedded in it, and extending so as to completely enclose the contracted polypites. *Polypites*, with a conical proboscis, in contraction strongly fusiform or nearly spherical; tentacles about eight. *Gonophores* numerous, produced on the stems, borne on long peduncles, often slightly ringed at irregular intervals, and with a

delicate continuation of the polypary all over, and also a thin transparent layer of the gelatinous substance. *Gonozooid* not known.

This species appears to be a very well defined one, possessing, as it does, a combination of characters which separates it from any other described form. Its closest allies are *P. vestitus*, All., and *P. palliatus*, T. S. Wright. The former, however, has the polypary yellowish brown, with adherent particles of sand; there are no annulations at the base, and no gelatinous covering to the polypary: the gonophores, also, are only invested for about half their length by the polypary. *P. gelatinosus* agrees with *P. palliatus* in having the body of the polypite clothed up to the level of the mouth with a gelatinous envelope; but differs in the well-developed, ringed, occasionally much branched stems, and in the gonophores being borne on the stems, and not on the stolon. It is possible that when *P. vestitus* and *P. palliatus* have been rediscovered in any number in their original locality—the Firth of Forth—that then, as Mr. Hincks believes (" Brit. Hyd. Zooph.," p. 95), they may be shown to belong to the same form, and then this present species may go along with them. It certainly presents somewhat of a combination of the characters of the two. Until this is done, however, it seems best that it should remain separate, and rank as a distinct species.

In one colony, obtained from the south-west of Ireland, the creeping stolon was so closely reticulated as to form an almost continuous chitinous crust on the shell on which it was growing.

The species well illustrates the variability to which the different representatives of the genus *Perigonimus* are liable, and the danger of founding specific characters upon an individual colony. In the form represented in fig. 2 the stems are short, unbranched, and have the gelatinous envelope very thick. In the other form (fig. 3), from a different colony, the stems are much longer, more branched, and the gelatinous envelope only feebly developed. From careful comparison, however, and experience of a number of forms, I have no doubt but that they all belong to the same species.

Habitat.—From rather deep water, growing on shells inhabited by *Pagurus*. Station 133, Dingle Bay; depth, 40 fathoms.— (R. D. S.): Log 73, south-west of Ireland; depth, 50 fathoms.

Log 42, 9¼ miles south-west of Castletown. Berehaven; depth, 37½ fathoms.—(R. I. A.).[1]

Perigonimus (?) inflatus, n. sp.

(Pl. XIV., fig. 4.)

Stem erect, simple; *polypary* horn-coloured, smooth, firm, forming above a thin, delicate, cup-like enlargement, within which the polypite is largely retractile.

Polypite large, much swollen in contraction, borne on a neck-like extension of the cœnosarc; body generally pendent; tentacles 8; *gonophores* unknown.

In the absence of the gonophores, this form can only be referred provisionally to the genus *Perigonimus*; but there can be little doubt, from a comparison of it with other species, that it belongs to the genus. I have found numbers of specimens rising from stolons creeping over other zoophytes, such as *Sertularia abietina*. The stem appears to be always simple, and the polypary over the greater part is rather thick and firm; but a little below the base of the polypite it thins more or less suddenly, and extends to form a delicate covering to the neck-like prolongation of the cœnosarc and the body of the polypite. This thin portion is somewhat coated with fine earthy matter. Little of this occurs on the thicker portion of the polypary. Towards the base the stem is a little wrinkled. The natural position of the polypite appears to be that of drooping from the neck-like portion.

This species is most closely allied to the *Perigonimus nutans* of Hincks,[2] especially in the "large elevated polypites and pendent habit," which Mr. Hincks regards as the striking feature in his species. It differs from it, however, in that the polypary extends to form a cup-shaped enlargement, within which the polypite is retractile, in the greater firmness of the polypary, and in the slight wrinkling towards the base. It does not appear to be such a

---

[1] In the present communication I have also recorded some of the examples which were collected by the Royal Irish Academy Survey of the South-west Coast of Ireland, 1885, '86, '88. For the Report on the Hydroida of these collections, see Proc. Roy. Irish Acad., 3rd Ser., vol. iii., No. 1.

[2] Ann. and Mag. N. H., Ser. 4, vol. xix., p. 149, pl. xii., fig. 1.

delicate form as *P. nutans.* The differences amongst the numerous described species of this genus are often very slight; and it seems not at all improbable that these two may ultimately be united, if it can be shown that the nature of the polypary is variable as to the formation or otherwise of an enlargement for protection to the polypite. It may possibly be that the polypary changes with age, and that the enlargement and firmness not distinguishable in Hincks's examples may appear later. Only by a study of numerous examples in the living state can this be determined; but until the point is settled, it seems best that *P. nutans* and *P. inflatus* should remain separated, if only to stimulate further inquiry.

This new species we owe to the labours of the Royal Irish Academy Survey of the South-west Coast of Ireland, but it seems best to insert it on the present occasion.

Habitat.—Growing on *Sertularia abietina*, and other zoophytes from deep water off the south-west coast of Ireland. Obtained on material trawled from two distinct localities:—Log 72, 11 miles south of Glandore Harbour, from a depth of 54 fathoms; Log 37, 13 miles south-west of Galley Head, from a depth of 43 fathoms.—(R. I. A.).

Bimeria vestita, T. S. Wright.

A single specimen of this peculiar form was collected from St. 240, Lough Swilly; depth 6 to $8\frac{1}{2}$ fathoms. It does not appear to be at all common around the Irish coasts, as this is the first time it has been recorded for the country. It is known from several British localities.

Bougainvillia fruticosa, Allman.

In correspondence with Mr. Hincks, I submitted to him a form of *Bougainvillia* loaded with gonophores, which appeared to agree with his description of an intermediate form, mentioned on p. 112 "Brit. Hyd. Zooph.," and figured on pl. xix., fig. 3. He agreed with me in my determination of this form. However, comparing it carefully with the description and figures of Allman's *B. fruticosa,* I fail to find any character of importance in which my specimens differ from that species. The stem is sub-alternately branched; the polypites are incapable of retracting themselves

within the expansion of the polypary to the same extent as in *B. ramosa*, and the gonophores are distributed over the ramules, as in Allman's well-known figure in the Gymnoblastic Hydroids. It differs from Allman's description in having the outer surface of the polypary covered with very fine foreign particles, giving it the appearance of being sanded over. Considering that the locality agrees approximately with that from which Professor Allman obtained his specimens, I have less hesitation in regarding these forms as the same. *P. fruticosa* was first collected from Kenmare River, Co. Kerry, while the specimens I have under consideration came from Bantry Bay. They consist of numerous small portions obtained growing on the limbs of a *Stenorhynchus*, which must have torn them from the parent colony to decorate itself with. On some of the specimens was one of the long fusiform parasite capsules, which serve as nests for larval Pycnogonida. I have also found these capsules, of somewhat similar shape, on *B. ramosa*, so that they cannot be regarded as characteristic of one species.

Campanulina turrita, Hincks.

(Pl. XIV., figs. 5 and 6.)

Stem distinctly ringed throughout, either short and simple, or crowdedly branched, and somewhat zigzag in shape; at each bend a branch given off, which generally branches immediately. *Hydrothecæ* with almost parallel sides in the middle, but narrowing slowly towards the base, and with an operculum composed of short, convergent segments. *Polypites* with about 18 tentacles. *Gonothecæ* broad, and sub-truncate above, tapering downwards, shortly stalked, and borne on the stem. *Gonozooid* closely resembling that of *C. acuminata*.

This species was first described by Mr. Hincks ("Brit. Hyd. Zooph.," page 190; pl. xxxvi., fig. 2) from drawings supplied him by Professor Wyville Thomson. Having since supplied Mr. Hincks with specimens collected from different parts of the Irish coast, he draws attention in a letter to me to the fact that Thomson's figure, and consequently the description based upon it, is erroneous in the method of branching. It is represented as if the ramules were given off in groups of two or three at each bend

in the stem. Examination of actual specimens shows, however, that only one is given off from the main stem at each bend; but this generally gives off another quite close to its origin. The abundance and approximation of the branching gives a very crowded appearance to the colony. The hydrothecæ in Thomson's figure are also a little too elongated.

The species appears capable of existing under two very different habits. In one case the creeping stolon gives rise only to short-ringed pedicels, each bearing a single polypite. When first I obtained this form I was under the impression that it was an entirely new species. Subsequently, however, I found examples creeping over *Crisia* in which, besides this simple habit, there were springing from the same stolon some in which the pedicels became more elongated, and others in which the stems were abundantly branched, as in the more common form.

The gonothecæ do not seem to be abundant. I have obtained them on colonies from Blacksod Bay and from Dursey Island. Although the species has been found from localities all round the Irish coast, it apparently has not been recorded from other parts of the British Isles.

Habitat.—Very abundant on *Zostera*, Holywood, Belfast Lough (Professor Wyville Thomson) : Blacksod Bay (R. D. S.) : Bantry Bay, on *Crisia*. Dalkey, on other zoophytes. Bundoran, Donegal Bay, on *Algæ*. Dursey Island, on *Laminaria* and *Coryne*. Roundstone, Connemara, on *Zostera*, (J. E. D.).

Campanulina panicula, G. O. Sars.

(Pl. XIV., figs. 7 and 8.)

Stem erect, branched, straight; slightly annulated at the origin, springing from a thread-like stolon forming a complex network over other foreign bodies, terminating in a hydrotheca; branches arising alternately, three or four annulations at their origin, smaller than the stem, either no further branching, each supporting only a single polypite, or divided dichotomously once or twice. *Hydrothecæ* very thin, obconic; not sharply marked off from the pedicels, closed by an operculum formed of numerous long convergent segments. *Polypites* capable of great extension. *Gonothecæ* and *Gonozooid* not known. *Height*, 1 cm.

This species was first found and described by Professor G. O. Sars from Dröbak, in Christiania Bay,[1] where it is a rare form. It has apparently not been obtained before from British waters. It was found growing profusely on two *Fusus* shells inhabited by hermit-crabs, trawled by the Survey from a depth of 220 fathoms off Achill Head.

It is a delicate species, and the polypary is quite colourless in spirit specimens. The polypites are very fragile, and capable of great extension. The stem is perfectly straight and upright, and the branches are given off mostly alternately. The examples obtained from the west coast of Ireland agree with Sars's description and figures of the Scandinavian specimens, except that the branching is not so prolific. This character, however, seems liable to considerable variation. On some stems most of the branches will be simple, only two or three presenting a bifurcation, and then these are near the apex. Other stems have the majority of the branches divided. In Sars's specimens a second bifurcation occurs, producing an appearance quite suggestive of the specific name.

Owing to the fact that the reproductive bodies are not known, the exact generic position cannot be determined, but there seems little doubt from the form of the hydrothecæ and the polypites that it is a species of *Campanulina*.

Many of the pedicels, and often the upper part of the stem, have occasional annulations, suggestive of frequent renewal of the polypites and extension of the polypary.

Habitat.—On *Fusus* shells, from deep water off the west coast of Ireland. Two shells, each with a large number of stems, were trawled by the Royal Dublin Society's Survey, at a distance of 40 miles off Achill Head, from the great depth of 220 fathoms.

POLYZOA.

The Polyzoa collected by the Survey, although numerous, are not of such great interest as the Hydroids. Some of them have already been noticed.[2] The important additional Irish localities

[1] Forhand. Videnskabs-Selskabet. Christiania, 1873, p. 121, pl. v., figs. 9–13.

[2] "On Some New and Rare Irish Polyzoa," Proc. Roy. Irish Acad., 3rd Ser., vol. iii., pp. 121–136.

for the rarer species will be found in the List of Irish Polyzoa which is in preparation.

The following species call for somewhat more special notice :—

Bicellaria Alderi, Busk.

This rare form was found growing on *Flustra Barleei*, Busk, from Station 114, off the Skelligs, at a depth of 80 fathoms. Only a small portion was obtained, but it exhibits all the distinctive features of the species. As usual in British examples, contrasted with Scandinavian, the avicularia were absent. Like the *Flustra* on which it was growing, this is the first time it has been recorded for Ireland, and it has only previously been found in British waters from the Shetlands by Mr. Barlee and Canon Norman.

Flustra Barleei, Busk.

A large colony, nearly 2 inches in height, was trawled from off the Skelligs, along with the previous species. In the large unarmed rectangular cells and oblique position of the avicularia it is easily distinguished from the other more common Flustras. The immersed ovicells are well shown in this Irish specimen. The species has only previously been obtained from British waters by Mr. Barlee, from Shetland, and "between Whalsey and Balta, and off Unst," by Canon Norman. The present occurrence considerably extends its southern range.

Triticella Boeckii, G. O. Sars.

This species, previously only known from Christiania Sound, was first recorded by me (*l. c.*, p. 131) for British seas, as having been obtained by the Royal Irish Academy Survey from Berehaven, growing on *Portunus depurator*. On two or three different occasions the Royal Dublin Society's Survey trawled it in Kenmare River, in each case growing on *Gonoplax angulata*. Only a few individuals were present on one specimen, as the crustacean appeared to have lately shed its shell. Another *Gonoplax* was almost covered with large scattered clusters, they being especially abundant on the antennæ. Both the peduncles and zoœcia are very variable in size according to their position in a dense cluster. The more central ones are much longer, and quite overtop the others. A third *Gonoplax* had its shell also partially coated with the Polyzoan.

Triticella pedicellata, Alder.

In the communication above mentioned, I also recorded (p. 133) this rare British species as having been trawled by the Royal Dublin Society's Survey from two localities—off the Skelligs, depth 80 fathoms, growing on *Buccinum undatum* and *Natica catenularia*; and also off Slyne Head, depth 55 fathoms, on *Trochus magus*.

Barentsia nodosa, Lomas.

Also previously mentioned (*l. c.*, p. 136) as being collected by the Royal Dublin Society's Survey from Killybegs and Smerwick Harbour, growing on *Algæ*.

A block of limestone, perforated by boring molluscs, was trawled from the great depth of 500 fathoms, at a distance of 45 miles off Blackrock, west of Ireland. It is interesting to note that the following species of Polyzoa were found encrusting it :—

Schizoporella linearis, Hass., very abundant. *Mucronella variolosa*, Johnst. *Smittia reticulata*, Macgl., and *Diastopora patina*, Lamk., in abundance.

This is probably the greatest depth from which some of these forms are known. *Retepora Beaniana*, King, was also trawled from the same depth at the same time.

[Explanation of Plate.

EXPLANATION OF PLATE XIV.

———

Fig. 1.—*Perigonimus repens*, T. S. Wright. Magnified.

Fig. 2.—*Perigonimus gelatinosus*, n. sp. Polypites retracted within the gelatinous envelope. Magnified.

Fig. 3.—*Perigonimus gelatinosus*, n. sp. More branched form, with polypites extended. Magnified.

Fig. 4.—*Perigonimus inflatus*, n. sp. Magnified.

Fig. 5.—*Campanulina turrita*, Hincks. Showing arrangement of branching. Magnified.

Fig. 6.—*Campanulina turrita*, Hincks. Reticulated stolon, with only single polypites on short pedicels. Magnified.

Fig. 7.—*Campanulina panicula*, G. O. Sars. Stem, slightly enlarged

Fig. 8.—*Campanulina panicula*, G. O. Sars. Portion of stem with branch. More enlarged.

XLII.

ON THE CHEMICAL EXAMINATION OF ORGANIC MATTERS IN RIVER WATERS. By W. E. ADENEY, F.I.C., Associate of the Royal College of Science, Ireland; Curator in the Royal University of Ireland.

In the paper which I brought before the notice of the Society last month[1] I gave the results of an extended experimental inquiry, which showed that the fermentation of organic substances, containing nitrogen, or mixtures of them with ammonium compounds, takes place progressively in two distinct stages in the presence of mixed organisms natural to surface waters—*aerobic conditions being continuously maintained throughout the mass of the fermenting liquid.*

It was demonstrated by those results that during the first stage the organic matters—nitrogenous or non-nitrogenous— are completely broken down, the carbon and nitrogen (if present) being almost entirely converted into carbon dioxide and ammonia, a small quantity of organic matter remaining as such, but in an altered form; and that, during the second stage, the ammonia is oxidized to nitrous or nitric acids, or both, and that at the same time the organic matters, formed during the first stage of fermentation, may be partially or completely oxidized, carbon dioxide and possibly nitric acid being formed; and that further the second stage does not commence until the conclusion of the first.

---

[1] Scientific Trans. Royal Dublin Society, vol. v.

The results of this inquiry further showed that careful determinations of the more obvious products of each stage of fermentation, viz. carbon dioxide and of ammonia during the one, and of carbon dioxide (if formed), and nitrous and nitric acids during the other stage, together with accurate determinations of the dissolved atmospheric oxygen consumed during both stages, afford data by which both the character and actual quantity of fermentable matters, present in a polluted water, could be estimated with sufficient accuracy for the purpose of water analysis.

In this short paper I propose to give an example of the application of this method of inquiry to the examination of the water of a small stream for unfermented, or, in other words, polluting, organic matters.

At the time when the samples, with which I experimented, were collected, the volume of water flowing through the stream was very small, probably not equivalent to as much as 100,000 gallons per day. The stream consisted almost, if not entirely, of drainage waters from cultivated land, and received, some little distance above the points at which my samples were taken, considerable volumes of drainage matters from neighbouring houses, a portion of which, however, had been subjected to a process of purification before being allowed to flow into the stream.

Two samples were collected on the 28th April, 1894, at 1 p.m. One sample was taken from a point about 200 or 300 yards below the lowest discharge of house drainage, above referred to ; the second sample was gathered from the lower end, and near the outlet, of a small pond-like enlargement of the stream at a point about 100 or 200 yards below the first. In this second case the sample collected was taken at a depth of about one foot below the surface of the water.

The bottles in which the two samples were collected were completely filled and carefully stoppered, and conveyed without delay to my laboratory. Both examples were examined by the ordinary method of analysis as well as by the method of examination above referred to, on the afternoon of the same day as that on which they were collected.

The ordinary method of analysis gave the following results :—

Constituents expressed as parts per 100,000.

	No. 1.	No. 2.
Nitrogen as free ammonia, ...	0·440	0·130
Nitrogen as albuminoid ammonia, .	0·006	0·010
Nitrogen as nitrates, ...	0·992	1·084
Nitrogen as nitrites, ...	0·024	0·018
Chlorine, ...	6·5	6·8

Sample No. 1 was slightly turbid but practically colourless ; it contained a small quantity of matter in suspension. Temperature at the time of collection was 54°·5 Fahr.

Sample No. 2 was very slightly turbid, but colourless, and practically free from suspended matter. The temperature when collected was 52°·5 Fahr.

Both samples were neutral to test-papers.

The above results led to the conclusion that the stream water, at both points represented by the samples, contained very little organic matter in solution, and that nitrification of ammonia was possibly rapidly proceeding in it.

When, however, the history of the stream was taken into consideration, it seemed extremely likely that these organic matters were largely, if not entirely, unfermented, and that it was quite possible that denitrification, rather than nitrification, was going on in the water, more especially as nitrous acid was found in distinct quantities in both samples.[1]

These doubts could, as I have shown in my former communication, be definitely settled by allowing the waters to ferment out of contact with air, and determining the changes in composition of the dissolved gases and inorganic nitrogenous bodies which would result. As I anticipated these doubts, I first analysed the dissolved gases in a portion of each sample immediately on uncorking the bottles in which they were collected, and, at the same

---

[1] See R. Warrington, F.R.S., on " The Chemical Action of some Micro-organisms," —C. S. J. 53, 742. Also J. H. M. Munro, D.Sc., on "The Formation and Destruction of Nitrates and Nitrites in Artificial Solutions, and in River and Well Waters." —C. S. J. 49, 667.

time, I put up other portions for fermentation, both operations being carried out as described in my former Paper. I was, however, unable to examine these latter portions for the results of fermentative changes until nearly seven months afterwards, viz. the following November, owing to pressure upon my time by other duties.

In the following Table the results of analysis, before and after keeping, are given :—

Gases expressed in c.cs. at 0° and 760 mm., bar., and other constituents as grammes, per 1000 c.cs. of water.

Sample	Date of commencement and of conclusion of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
No. 1	April 28, 1894,	116·05	5·99	15·08	·0044	·00024	·00992
,,	Nov. 21, 1894,	123·68	0	17·17	·0050	0	·00900
	Differences,	+ 7·63	− 5·99	+ 2·09	+ ·0006	− ·00024	− ·00092
No. 2	April 28, 1894,	116·39	7·38	15·58	·0013	·00018	·01084
,,	Dec. 12, 1894,	119·71	0	15·63	·0006	·00016	·01174
	Differences,	+ 3·32	− 7·38	..	− ·0007	− ·00002	+ ·0009

The fermentative changes recorded in the preceding Table show at a glance the character of the organic matters in the two samples of water.

It is evident, for example, that the organic matter in sample No. 1, or a portion of them, had not undergone fermentation at the time the sample was collected. This is shown by the fact that not only was the free ammonia increased in quantity by fermentation, but that all the nitrous acid and a portion of the nitric acid were reduced. Evidence of the reduction of the then two bodies is afforded not only by decreased quantities of nitrogen as nitrous and nitric acid shown after fermentation, but also in the increase in volume of the dissolved nitrogen.

It may indeed be stated in the light of the experimental evidence given in my former Paper, that the fermentative changes recorded for the sample No. 1 was entirely confined to those

which characterize a first stage fermentation, viz. a breaking down of unfermented organic matter, and a conversion of its carbon and nitrogen into carbon dioxide and ammonia.

The results given for the second sample show that, notwithstanding the fact that it yielded a decidedly larger quantity of albuminoid ammonia than the first, it contained much less unfermented organic matter, and that in consequence, we have less carbon dioxide formed ; and instead of ammonia being formed, more than half of that originally present was oxidized to nitric acid.

Judging from the quantity of dissolved oxygen consumed, and the quantities of carbon dioxide and nitric acid formed, we may safely regard the former product as a result of a first-stage fermentation; the latter product resulted, of course, from a second-stage fermentation or true nitrification.

If these experiments had been carried farther, as they could have been in the manner described in my first Paper, it would have been possible to have determined the exact volume of oxygen necessary for the complete oxidation of both the unfermented organic matters and ammonia present in each sample.

They go sufficiently far, however, to render it possible to draw definite conclusions as to the extent of pollution of the stream water by organic matters at the two points examined. In the first place, both samples were highly oxygenated at the time they were collected, sample No. 2, more especially, notwithstanding the fact that it was collected a foot below the surface of the stream. It may therefore be concluded that, since both samples were neutral to test-paper, and were therefore in a condition favourable to bacterial fermentation, the organic matters were present in too small quantities to encourage a bacterial growth sufficient to cause a rapid consumption of the atmospheric oxygen dissolved in the water, and thereby to endanger fish or the higher forms of vegetable life.

In support of this conclusion, that fermentation was proceeding very slowly in the stream at the points examined, I may quote an experiment which I made with a sample of the stream water gathered a few days previous to that on which the two samples under discussion were collected.

The sample was taken from much the same part of the stream as sample No. 2, and also one foot below its surface.

The dissolved gases and other significant constituents were determined on the day of collection, and a portion of the sample was preserved out of contact with air for a period of four days, and again examined.

The results obtained were as follows :—

Date.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
April 20, 1894, . . .	119·26	5·98	16·44	·0009	·00018	·00952
April 24, 1894, . . .	120·56	5·32	16·38	·001	·00012	·00938
Differences,	+ 1·30	− ·66	..	..	..	..

The sample was slightly turbid, practically colourless, and contained no suspended matters. It was neutral. When first collected it yielded ·005 grms. N as albuminoid ammonia per 100,000 c.cs. of water.

These results show that even during the comparatively long period of four days, only ·66 c.cs. of oxygen out of a total of 5·98 c.cs. per litre were consumed. Had considerable quantities of fermentable organic matters been present in the water, there can be no doubt, from the experiments recorded in my first Paper, that the oxygen would have been absorbed in a few hours after fermentation had set in.

It will be noted that the time given for fermentation, in the case of samples Nos. 1 and 2, was seven and eight months, respectively. This length of time was not necessary, but was unavoidably allowed for the reason I have already stated.

In a neutral water containing so small a quantity of fermentable organic matter as each of these two samples, the time necessary for the first stage fermentation, judging from experiments recorded in my first Paper, would not exceed one month ; and that required for the completion of the two stages, the final result of which would be the complete oxidation of all ammonia present, would not exceed two months.

I need scarcely dwell upon the great power which this new

method of examination, compared with those hitherto in use for the examination of river waters, places in the hands of chemists for gaining a knowledge of the true character of the fermentable matters to be found in river water. I would, however, again draw attention to the important fact which I dwelt upon in my first communication, viz. that it is possible to determine by means of this new method not only the total volume of oxygen required for the complete oxidation of the fermentable matters, including ammonia, in water, but also to distinguish the portion consumed during the first stage of fermentation from that consumed during the record stage—a distinction, for reasons I have already given, of the utmost importance in connection with the technical consideration of the pollution of river water.

XLIII.

BRANCHED WORM-TUBES AND ACROZOANTHUS.
By PROFESSOR A. C. HADDON, M.A., F.Z.S.,
Royal College of Science, Dublin.

NUMEROUS specimens of *Lophohelia prolifera* were dredged at a depth of 220 fathoms, fifty miles off Bolus Head, county Kerry, during the Society's Fishery Survey.[1]   Most of these are infested
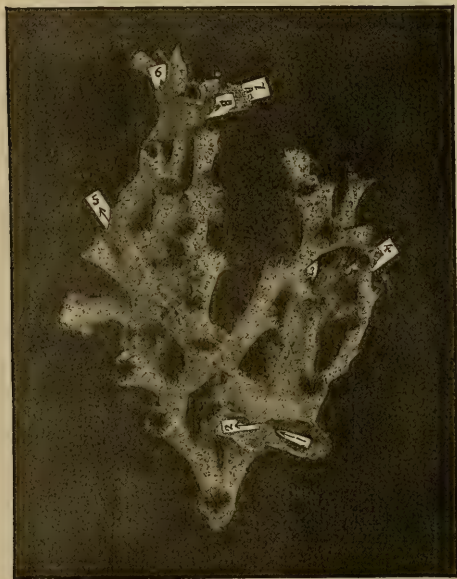
by the tubes of *Eunice philocorallia*, Buch. Miss Buchanan[2] refers (p. 174) to the commensalism of the worm with the coral, and

[1] E. W. L. Holt : " Survey of Fishing Grounds," etc., Proc. R.D.S., VII. (N.S.) 1892, p. 261.

[2] "Report on Polychæts, collected during the Royal Dublin Society's Survey off the West Coast of Ireland.   Part I.—Deep-Water Forms."   By Florence Buchanan. Proc. R.D.S. VIII. (N.S.) 1893, p. 169.

states that the worm to some extent modifies the growth of the coral, the coral growing round the worm-tube which thus becomes embodied in the cœnenchyme. Although Miss Buchanan describes the tubes as having a " parchment-like consistency, with jagged lateral openings," she does not allude to the branched character of the tube, nor does this appear in her plate xi. I have therefore thought it advisable to draw attention to this character, and to figure a specimen (p. 334) which exhibits it in a fairly satisfactory manner.

I have indicated by numbers all the orifices in the tube, and there were probably several others, as the specimen figured is only a fragment. Immediately after the side branch at 2, the tube divides into two main branches, the one has two orifices, the other has four, three of which are close together, and diverge something like the crown tines of a deer's antler.

In the Zoological Department of the Royal College of Science, there is a somewhat similar worm-tube associated with *Oculina virginea*; but the commensal worm is unknown, and the locality of the specimen is unrecorded. In this specimen there are six lateral openings, most of which are at the extremities of short branches, and there are indications of two other orifices which have been covered by the cœnenchyme of the coral.

Professor E. Ehlers,[1] in his Report on the Annelida collected on the " Blake " Expeditions, describes the branched tubes of the following Polychætes:—*Eunice floridiana*, *E. tibiana*, and *E. conglomerans*. The first species has lamellose papyraceous tubes, often variously contorted with lateral ragged openings irregularly placed, though, in general, alternate. In *E. tibiana* the sub-pellucid horny tube is either cylindrical and straight, or regularly serpentine; at every bend there is a tubulated aperture directed backwards, with an expanded fimbriated border.[2] Lastly, the whitish paper-like tube of *E. conglomerans* has only a single orifice, one end is closed, and there are several spots and prominences which also appear to have been once open, and subsequently closed over.

---

[1] "Florida—Anneliden." Mem. Mus. Comp. Zool., Harvard, xv., 1887.
[2] The description of this and the preceding tube have been compounded from Ehlers' and from L. F. de Pourtales' " Contributions to the Fauna of the Gulf Stream at Great Depths." Bull. Mus. Comp. Zool. Harvard, No. 6, 1867, p. 108.

Professor W. C. M'Intosh[1] refers to the tough, parchment-like, slightly branched tubes of *E. Magellanica*; and he figures (fig. 28, p. 267) a distinctly branched tube of an unknown worm from the Gulf of Manaar, which is commensal with a horny sponge (*Hircinia clathrata*).

Other examples of branched worm tubes are known to occur, but these will suffice for my purpose.

Mr. W. Saville-Kent, in his magnificently illustrated book, " The Great Barrier Reef of Australia : its Products and Potentialities," described a new form of Zoanthean which he named *Acrozoanthus Australiæ*. He regards it as the representative of a new family, on account of the polyps growing on a branched parchment-like tube. Mr. Saville-Kent forwarded me a specimen for anatomical investigation; and I found that the polyp was of precisely the same structure as those species of the genus *Zoanthus* which I have investigated, the differences being so small as not to amount to more than specific distinctions. I also stated that I considered it as a new species of *Zoanthus*, which was associated with a worm-tube. In his book Mr. Saville-Kent discusses this point, but as he was unaware of the occurrence of branched worm-tubes, he considered this peculiarity as an insuperable objection to my view. He says : " Such an interpretation would involve the improvisation of a far more abnormally constituted worm than Zoophyte " (p. 154).

I have seen several tubes of " Acrozoanthus," and all the forms of branching, and the closure of some of the lateral openings can be paralleled among the tubes of the various species of *Eunice* referred to above. On one tube (Taf. 27, fig. 2) of *E. tibiana*, in Dr. Ehlers' Memoir, will be seen disc-like bodies, some of which are represented with radiating lines. These have every appearance of dried and contracted specimens of a Zoanthean, possibly an *Epizoanthus*. If this identification is correct, other branched worm-tubes may be associated with Zoantheæ.

I propose therefore to abolish the genus *Acrozoanthus*, and to place Mr. Saville-Kent's form under the genus *Zoanthus*, as *Z. Australiæ* (S.-Kent).

---

[1] Report on the Annelida Polychæta. Challenger Rep. vol. xii., 1885, p. 1.

XLIV.

A METHOD OF INCREASING THE POWER OF CONTINUOUS
LIGHTHOUSE LIGHTS. By JOHN R. WIGHAM, M.R.I.A.,
Member of the Council of the Royal Dublin Society.

FROM this title it will be seen that I do not propose to bring
under the notice of the Society any new lighthouse illuminant.
On a previous occasion I brought before this Society what I believe
was *then*, and still *is*, the most powerful lighthouse light, viz. the
intensity burner with the giant lens. On this occasion I propose
to describe a method of increasing the efficiency of *any* lighthouse
light, not by increasing the power of the illuminant, but by
altering the method of the application of the optical apparatus
with which it is associated, so as to give continuity to revolving
lights and greater power to fixed lights. Notwithstanding the
many names by which lighthouse lights are distinguished, there
are practically but two classes into which they can be divided, viz.
fixed lights, and revolving or flashing lights. The light of " fixed
lights " is generally transmitted through refracting belts and
prisms. On placing a burner in the focus of the apparatus the
vertical light is refracted in parallel rays, the horizontal light being
allowed to proceed to every part of the horizon without reflection
or refraction. The effect of this fixed light apparatus at a short
distance (say about 100 feet) is to produce a column of light the
height of the apparatus and the breadth of the burner. It is, of
course, immensely less powerful than the light which is trans-
mitted by annular lenses by which the light is parallelized, both
vertically and horizontally, into beams, transmitting to the observer
all the light from the burner which falls upon them. In order
to send these beams to every part of the horizon the lenses must
of necessity be caused to rotate, and this constitutes the revolving
light of lighthouses.

The system of revolving lights is, however, subject to this disadvantage, that during the periods of darkness which succeed each exhibition of the light the position of the light is lost, and in some states of the weather, especially in thick weather, is not again easily found. It is no wonder that sailors should consider it a consummation devoutly to be wished that the superior power and characteristic appearance of the revolving light should be combined with the permanent continuity of the fixed light.

About the year 1820, Capt. Basil Hall, R.N., conceived the idea that if annular lenses were caused to revolve with such velocity that the beam from each should blend into a continuous light (like the luminous circle caused by whirling through the air any incandescent object), this *desideratum* would be attained. The matter was carefully investigated by the Commissioners of Northern Lights, and the sum total of their report was, that the difference of volume between the light of a cylindric refractor and that produced by the lenses at their greatest velocity was very striking. The former presented a large diffuse object of inferior brilliancy, while the latter exhibited only a sharp pin point of brilliant light. They were therefore discouraged from attempting to improve the visibility of fixed lights in the manner proposed by Captain Hall.

Thus matters remained until the subject was again brought to the front by the French lighthouse authorities. Certain French physiologists had pronounced the opinion that the power of any light can be enjoyed to the full if it be presented to the eye for one-tenth of a second. Acting on this physiological law, the engineers of the French lighthouse department availed themselves of it, and constructed the new Cape La Heve lights. These lights only remain in the eye one-tenth of a second, and recur every five seconds.

The new light to which I now desire to call attention rests in the eye one-fourth of a second, and, unlike the French light, never leaves it, *i.e.* the light is continuously visible. The flashes of which it is composed are practically the same in volume and intensity as those of the ordinary slowly revolving light, and being always in the eye, there is no period of darkness during which the sailor may lose the position of the light. Anyone who has been in the habit of looking at revolving lights must have

observed that when, after an interval of darkness, the light re-appears, it always seems to do so at a place different to that from which it had disappeared. This is due, of course, to the insensible wandering of the eye during the time of darkness.

The apparatus is composed of 8 annular lenses of 45° each; the octagonal figure which they make is rotated at a speed of two seconds for each complete revolution. The impression produced on the retina by the flash from one lens remains until replaced by the flash of the next, and consequently a continuous pulsating effect is produced. Thus, it not only fulfils the conditions to which I have referred, but constitutes a light of an entirely new characteristic appearance, well calculated to arrest the attention of the mariner by its continual pulsation.

I will now briefly bring under your notice another example of the usefulness for lighthouse purposes of the principle of which we have been speaking, viz. the capacity of the eye to receive the impression of a light if presented to it for a time so short as one-tenth of a second. This application has nothing to do with lenses, but consists simply in the rapid extinction and re-ignition of the light of a gas-burner. If, instead of extinguishing and re-igniting the light at intervals of about two seconds, as is done in the group-flashing lights at Galley Head, Mew Island, and Tory Island, we cause the extinctions and re-ignitions to succeed each other with great rapidity we produce the effect of a con-tinuous light, a light which never leaves the eye, and yet produces upon the retina a fluctuating effect, which is another of the dis-tinctive characteristics to which I have referred. When this is combined with the lenticular apparatus above described, the effect is very striking. The light is always visible, with its character-istic shudder, and further, it must not be forgotten (in these economic days), that in this case half the illuminant is practically saved. Indeed, neither of these devices for increasing the efficiency of lighthouse illumination is costly in application, and, at comparatively little expense, existing lighthouses may be altered to receive these improvements without the addition of expensive apparatus, so that the objection which is frequently raised by lighthouse authorities, that there is no money to spare for lighthouse improvement, does not hold good in this case. It may, therefore, be reasonably hoped that lights on this principle

will soon find their way into the general lighthouse systems, not only of the United Kingdom, but also of other countries.

The Paper was illustrated by the exhibition of a "fixed light" dioptric apparatus with a Wigham gas-burner lighted in its focus, also a group of annular lenses, the focal light of which was similar to that at Tory Island lighthouse. The light of this group was automatically cut off and restored by the machine which rotated the lenses.

XLV.

OF THE KINETIC THEORY OF GAS, REGARDED AS
ILLUSTRATING NATURE. By GEORGE JOHNSTONE
STONEY, M.A., D.Sc., F.R.S., Vice-President, Royal Dublin
Society.

Science may be defined as the investigation of how nature works,
of how and why events in nature occur.

This investigation is best carried on by employing the Physical
Hypothesis, viz. that the objects of nature act on one another,
either directly (action at a distance), or through intervening media
(which by many is supposed to be an essentially different kind of
action). Now, the objects of nature, in the more strict sense of
that phrase, are syntheta of human perceptions and ultra-percep-
tions ; and syntheta of perceptions cannot be what really act.
Nevertheless, it is eminently useful to carry on our investigation
under the physical hypothesis that it is they which act, and to
confine our efforts to tracing out what effects this action must be
supposed capable of producing, and under what laws it must
operate, in order that it may account for what occurs in nature.
This, however, is felt by many persons to be too abstract an
attitude of mind ; and to satisfy them, and create the plausibility
which they demand, by relieving the fundamental conceptions of
what is oppressively felt as the absurdity of supposing that syn-
theta of perceptions act, it is usual to supplement these syntheta
by piling an aërial Pelion upon this solid Ossa, and by supposing
that in addition to the *sensible object* which occupies any portion
of space there is what is called *its material substance* occupying
the same position, which, partly directly and partly by its motions,
acts on other material substances [the æther being one of these
material substances]. According to this, which is the prevalent
hypothesis among both scientific and non-scientific men, it is these
substances which travel about through space ; and the sensible

objects, which are what we see and feel, are supposed to accompany them in their wanderings by reason of the way in which they, the substances, act (usually through intermediate material agencies) upon our organs of sense.[1]

This is the usual point of view : but more careful thinkers will do well[2] to eschew this somewhat convenient, but by no means necessary, encumbrance upon the unadulterated process of physical investigation which treats the sensible objects themselves, the bare syntheta of perceptions and ultra-perceptions, as though they were what brought about the changes that occur in nature ; and which exclusively occupies itself in tracing out the laws that must, under this hypothesis, be in operation in order that the effects may be what they are.

Another and a very useful scaffolding which helps us in building up our investigation, is the introduction of forces between the physical cause (which is always the vicinity of some natural object) and the effect to be attributed to it under the physical hypothesis. We are thus enabled to speak of the acceleration of a stone in its fall towards the earth either as being due to the neighbourhood of the earth, or as being caused by a force of gravitation which acts on it, which force is, in its turn, regarded as brought into existence by the proximity of the earth to the stone. The introduction of this piece of intermediate scaffolding is of great service—

1. Because the force can be represented by a line whose length accurately represents the intensity, and whose direction accurately represents the direction of the effect upon the stone of the vicinity of the earth ;

2. Because the same effect upon the stone might have been due to other physical causes, as, for example, to a spring urging it forward, in which case the same piece of scaffolding, a force

---

[1] The author has endeavoured to trace out what it is that really occurs in all such cases. See his paper " On the Relation between Natural Science and Ontology " in the Scientific Proceedings of the Royal Dublin Society, vol. vi. (1890), p. 475.

[2] This course is much to be preferred, because it effectually avoids the risk of throwing dust in our own eyes. The justification of the Physical Hypothesis is its utility, not its truth—its incomparable efficiency as a means of investigating nature ; and it is better, though not essential, that students of Physics should make no mistake about a matter of this kind.

represented by the same line in the same position, would occupy its place between the cause and the effect; and

3. Because the effect might have been different, while the physical cause remained the same—thus, if the stone lay on the ground, what the vicinity of the earth would have occasioned is stress between the stone and the ground.

Accordingly by referring effects in nature to the operation of forces, we are enabled in each case to indicate with accuracy the intensity and direction of the effect, without having to specify (*a*) which of several possible physical causes is the one in operation, or (*b*) which of the possible kinds of effect is that which is being produced : and this in practice is found to be an immense convenience.

Such is an outline of the principles that underlie the dynamical investigation of nature, which is the form of investigation that penetrates most deeply into its secrets.

The dynamical investigation of nature being the most complete from the physicist's standpoint, is of course to be preferred to any other wherever it can be employed. Our present knowledge of astronomy, of rigid dynamics, of elasticity, of hydrodynamics, are among its great achievements. But there are other sciences in which we cannot penetrate so close to the origin of things, but which are, nevertheless, amenable to mathematical treatment onwards from a station less deep-seated. In these we begin with happily chosen equations, the truth of which we have not succeeded in tracing to their dynamical source in nature, but the consequences of which we can calculate and compare with what we observe to occur. Of this kind are the exquisite theory of light which was developed by M'Cullagh, and the enormous strides which our knowledge of electricity has made within the last half century, culminating in the marvellous electro-magnetic theory of light.

In all such sciences we are greatly helped by mechanical illustrations, which may be regarded as working models, that, though they do not in the least profess to represent the unknown dynamical condition which exists in nature, furnish us with an apparatus which operates in ways that we can both compute and conceive, and which produces results that, in some important respects and within ascertainable limits, follow laws the same as

or analogous to those that prevail in the part of nature which is illustrated by them. Of this kind is that most useful and simplest wave-theory of light which represents it by an undulation of mere transverse vibrations. Of the same kind are the various attempts to represent the ' texture,' which must prevail in the luminiferous æther.[1]   And somewhat akin to these are those instructive analogies which can be traced out between different sciences, wherever in both the same differential equation governs the progress of events. Thus, when a current of electricity is turned on to a circuit, the current penetrates the wire from its surface towards its core, by the same law as that by which heat would, by conduction, be carried inwards from the surrounding dielectric— a process already familiar to us, and which, therefore, makes the sequence of events in the other case easily conceived.

Again it must be remembered that in every dynamical investigation, what the mathematician really investigates is not the problem presented by nature, but some simplication of it. The legitimacy of this process and its value depend upon the important circumstance that, in dynamics, a slight change in the data leads only, at least for a time, to a slight change in the result. Thus in computing the mutual perturbations of the planets, the planets may be treated as though they were spheres, made up of untextured spherical shells each of a uniform density throughout ; and it may be left out of account that they approach to being spheroids, with mountains on their surface, irregularities of a like kind at greater depths, rocks in those mountains, minerals in those rocks, a different molecular texture in each mineral, tidal strains, heat expansions by day, contractions by night, and so on—perhaps seas and an atmosphere, vegetation and animals, all in constant and complicated movement ; with numberless other details. Now it is legitimate to omit all these from our calculation, for though every one of them produces its effect in actual nature, the difference between the outcome of their joint operation and that computed from the greatly simplified data of the mathematician is too small to make any approach to being perceived by any human agency. Hence, for any purpose which is of use to man,

---

[1] See these Proceedings, vol. vi. p. 392, or " Philosophical Magazine " for June, 1890, p. 467.

the approximation arrived at by the simpler problem is sufficient, wherever the errors are of such a nature that they are not cumulative. Nevertheless, it should be clearly recognized that it is a mechanism illustrating nature, and not nature itself, that has been mathematically investigated. So it is with all dynamical investigations : the data of nature have to be simplified to bring the task within the range of man's power over mathematical analysis ; and the result is satisfactory because of the important fundamental principle referred to above, that in dynamics a slight modification of the data furnished by nature may be safely made, because it leads only to there being a small difference between the calculated result and that which occurs in nature—of course care being taken in each case that the approximation of the computed result to what occurs in nature shall be sufficiently close for the object we have in view.

These criticisms need to be pressed with special emphasis when we are examining investigations into the dynamical condition of gases. Here we have to substitute for the data of nature others which differ from them in undesirable ways and to an undesirable extent, in order to arrive at data simple enough to be available as a basis for mathematical deductions. Nevertheless, some of the results are not appreciably affected by this too great simplification of the data : for instance, those which are consequences of such general facts as that the molecules spend most of their time in travelling about in straight lines like missiles, without a preponderance of the kinetic energy of the motions in any one direction ; and the further fact that the interchange of energy which occurs during the encounters, and the immense number of these encounters, leads to a rapid distribution to other motions of any excess of energy which any one motion of any one molecule may possess, and thus both equalises the pressure throughout the gas, and establishes the prevalence of a constant average ratio between that portion of the energy which manifests itself in the journeyings of the molecules, and that which is occupied in internal motions of the *Ba* class.

In order to make this language intelligible it is necessary to explain that in treating of gases it is convenient to use the word *motions* in a generalized sense, so as to include both motions proper and all other events which are brought about by imparting

energy to the gas, and which thereby become depositories of energy. These motions or events may be first divided into the two classes A and B, external and internal events. The A or external events are simply the motions of the centres of inertia of the molecules between their encounters: the B events are rotations or other motions, or changes of configuration, of the parts of a molecule relatively to one another, or electrical or other events: any events in fact which can be brought about by an expenditure of energy. These may all be spoken of either as motions or events, using the term motions in its generalised sense.

Again, the B events require to be subdivided into three classes: Ba events, which readily exchange energy with the A events, *i. e.* which are affected by the speed with which two molecules plunge into one another when an encounter takes place, and which in turn contribute in a marked degree towards determining with what velocities they shall separate when the encounter is over. In contrast to these, the Bc events (if any such exist, as is perhaps probable if the vortex theory of matter is true) are such as are *completely* isolated from the A and Ba events, and therefore neither gain nor lose energy in the encounters. Between the Ba and Bc events stand Bb events, which seem to be a conspicuous part of what is actually going on in all the real gases of nature. These Bb events are not wholly unaffected by the encounters, but in any one encounter gain or lose but little energy; while after millions of encounters, the transference of energy, perhaps chiefly in one direction—from them to other events—may be appreciable. Events of this kind may produce even conspicuous effects in times which appear to us very short, since in the ordinary air about us each molecule meets with a million of encounters in something like the seventh part of the thousandth of one second of time. In attempting to interpret the results furnished by our dynamical investigations, the extraordinary [1] rapidity with which the molecular events succeed one another in the actual gases of nature must be fully allowed for.

Another matter to be kept carefully in mind is that most of the dynamical investigations go on the assumption that interac-

---

[1] See the description of an illustrative model in the last paragraph of this paper.

tion between molecules, and the interaction within a molecule of one part of the molecule upon another *are the only forces that intervene;* whereas in all actual gases there is also a continuous interchange of energy going on between some of the internal events of the molecules and the ocean of unceasing ætherial undulations in which they are immersed.

One most remarkable and instructive dynamical theorem is due to the keen insight of Clerk Maxwell and of Professor Boltzmann.

Maxwell discovered the important theorem that if generalised co-ordinates be used to represent the motion of any system of bodies, and if the *vis viva* can be expressed as a sum of squares of momenta[1] of these co-ordinates, then the average energy will, if once equally divided among the terms of this series, continue to be so divided.

Boltzmann has extended this theorem into the following :—

If the *vis viva* can be expressed as a symmetrical function of the second order of the momenta (which may include both squares and products) then momentoids—linear functions of the momenta—can be so constructed that the *vis viva* shall be a sum of squares of these momentoids multiplied by functions of the co-ordinates : and the average energy, if at any time equally divided, will thenceforth continue to be equally divided between the terms of this expression.

Under the Maxwell Theorem it is between the momenta, under the Boltzmann-Maxwell Theorem it is between the momentoids, that the equal partition of energy takes place. The number of the momentoids is the same as of the momenta, and each of these latter is associated with a distinct degree of freedom in the system. Hence, when the Maxwell Theorem holds, the energy is equally divided among the degrees of freedom ; but it is between certain quasi-groups of these degrees of freedom that the partition takes place under the Boltzmann-Maxwell Theorem. These quasi-groups, like the momentoids which define them, are of the same number as the degrees of freedom.

---

[1] A momentum may be defined as the differential coefficient of one of the co-ordinates with respect to time, multiplied by a coefficient which may be any function of the co-ordinates.

In most cases, where the only forces intervening are interactions between parts of the system, the energy can be expressed in the form required by the theorem. But this is not the case when certain external forces come into operation, as, for example, when the æther acts on molecules as well as the molecules or parts of a molecule on one another.

Nevertheless, the theorem is of value in the interpretation of nature, because in many cases the æther intervenes somewhat as perturbating forces do in the case of the planets, modifying but not annulling the dynamical condition which would prevail if the sun's attraction alone exercised dominion over them.

On the other hand, it must be remembered that such a vast number of molecular events are crowded together within a duration that appears very short to us, that small effects have superabundant opportunity of gradually accumulating and becoming conspicuous, within a small fraction (*e.g.* within the thousandth part) of one second of time.

In estimating the average energy, the average may be struck either over a great succession of events happening to one molecule, or over what occurs simultaneously to a vast number of molecules.

The importance and value of these results depend—

1. On the small volume and the short time, as estimated by what are involved in human experiments, which suffice for the requisite averages—each cube of a micron (the thousandth part of a millimetre) in the volume of the gas containing about 1000 millions of molecules[1] if it be under the same pressure and temperature as atmospheric air, and each of these molecules meeting with about seven million encounters within the thousandth part of one second.

2. They also depend on the principle recited above, viz.:— that if the data of a dynamical theorem be slightly altered, the conclusions are only disturbed to a small extent.

3. And they depend on the circumstance that the forces to be taken account of in applying the theorem, may be confined to such forces as are concerned in those events which either directly

---

[1] See Phil. Mag. for August, 1868, p. 141.

or indirectly influence the motions of molecules in their journeys between their encounters. If, accordingly, there be any events of the kind which we have termed *Bc* events, they and the forces concerned in them may be kept outside the theorem, and may exist and involve any amount of energy; which energy is, however, additional to that which in the theorem is regarded as the total energy, which is to be understood as the total of the energy of the events with which the theorem is concerned.

The following mechanical illustration, which is that usually employed, will enable us better to grasp the meaning and appreciate the value of these remarks. In it I will suppose the gas to be of one kind, with molecules that are all alike, and that the number of molecules and the average duration of a journey are what they are in atmospheric air at the surface of the earth.

The simplest way of fulfilling the condition that the expression for the energy shall be a sum of squares, is to provide a mechanical model in which the whole energy is kinetic; and the simplest way of securing this is to suppose each molecule to be a rigid elastic body, with a frictionless surface. The expression for the energy of the molecule will then take the familiar form—

$$T = \tfrac{1}{2}\left[M\left(u^2 + v^2 + w^2\right) + A\omega_1{}^2 + B\omega_2{}^2 + C\omega_3{}^2\right]$$

where the letters have their usual meanings. Here each term in the expression corresponds to one of the six degrees of freedom of the rigid body, and the theorem states that the time-integrals of the several terms of this expression are equal, and that the average value of T is $1/N^{th}$ of the total energy in the gas, N being the number of molecules; in other words, that the molecule exhibits one-sixth of its share of the total energy in each of the following ways, viz.:—1°, in its journeyings east and west; 2°, north and south; 3°, up and down; and 4°, 5°, 6°, in spinning on each of its three principal axes. To simplify the conception as much as possible, we may suppose our model of a molecule to be a smooth ellipsoid of uniform density.

Let us next represent the molecules by ellipsoids of revolution. The full expression for the energy of such a body is—

$$(1) \qquad T = \tfrac{1}{2}\left[M\left(u^2 + v^2 + w^2\right) + A\omega_1{}^2 + B(\omega_2{}^2 + \omega_3{}^2)\right],$$

but for the purposes of the theorem it may[1] be reduced to—

$$(2) \qquad T' = \tfrac{1}{2} \left[M \left(u^2 + v^2 + w^2 \right) + B \left(\omega_2{}^2 + \omega_3{}^2 \right) \right],$$

since rotation round the axis of symmetry can neither be set going by the kinetic energy with which the molecules collide, nor if maintained in any other way can it in the least influence the values of u, v, and w.

The model when dealt with in this way is instructive, because it illustrates, as Mr. Bryan has pointed out (Proceedings of Cambridge Phil. Soc. of Nov. 26, 1894) how a motion may exist in a molecule which does not come under the theorem, and which therefore may be going on with any amount of energy.

To describe the situation in other and very convenient language, the motions of translation of the ellipsoids of revolution between their encounters are A events, and the energy of these events, viz. :—

$$\text{Average value of} \quad \Sigma \, \tfrac{1}{2} \, M \left(u^2 + v^2 + w^2 \right)$$

is $\tfrac{3}{5}$ of the whole of that energy of the mechanical model which comes under the notice of the theorem.   The rotations ω_2 and ω_3 are Ba events, and their energy, viz. :—

$$\text{Average value of} \quad \Sigma \, \tfrac{1}{2} \, B \left(\omega_2{}^2 + \omega_3{}^2 \right)$$

is $\tfrac{2}{5}$ of the energy dealt with by the theorem.   The rotation ω_1 is a Bc event, which can be kept outside the theorem.   In it, accordingly, any amount of energy may reside.

Another instructive mechanical illustration is constructed by considering each molecule as a rigid ellipsoid of one uniform density surrounded by a rigid envelope of another uniform density, extending from the surface of the ellipsoid to the smooth surface

---

[1] It is very necessary to bear in mind that, so far as the theorem is concerned, it is optional with us whether we make this reduction from 6 to 5 terms or not.   But if we retain the term $\tfrac{1}{2} A \omega_1{}^2$, we must remember that the theorem only deals with motion subsequent to an initial condition *in which an equal partition of energy had been made* among the terms.   It states that *if* this condition existed initially, it will continue subsequently ; and this is evident so far as the rotation round the axis of symmetry is concerned, since, if this rotation were once set up, it would continue unchanged.   For some purposes we must retain the six terms, *e.g.* in order to see how the transition from the case of a solid of revolution to the case of a solid which differs but little from a solid of revolution, takes place without an abrupt change in the effect predicted by the theorem, so as to comply with the general principle of continuity in dynamics.

of an outer concentric sphere (see Bryan, *loc. cit.*). Such a complex molecule may represent a diatomic molecule with only three of its degrees of freedom operated upon during collisions. Here the energy of the molecule is

$$T = \tfrac{1}{2}\left[M\left(u^2 + v^2 + w^2\right) + A\omega_1^2 + B\omega_2^2 + C\omega_3^2\right],$$

whereas the part concerned in the theorem is only

$$T' = \tfrac{1}{2}M\left(u^2 + v^2 + w^2\right),$$

since the external surface being a smooth rigid sphere round the centre of inertia, the collisions cannot set up rotations.

In this case u, v, and w are A events; and, on the average, divide equally among themselves the share of energy coming to this molecule under the theorem. At the same time the rotations ω_1, ω_2, ω_3 are Bc events, and may be going forward, subject only to the equations of the rotation of a rigid body round its centre of inertia, viz. :—

$$T'' = \tfrac{1}{2}\left(A\omega_1^2 + B\omega_2^2 + C\omega_3^2\right),$$
$$G = A^2\omega_1^2 + B^2\omega_2^2 + C^2\omega_3^2.$$

Their energy T'' may, accordingly, be of any amount in each molecule separately.

We have hitherto had only A, Ba, and Bc motions in our illustrative models. Bc events are of little practical interest; whereas the study of Bb events is of much use, since they are probably present in large amount in actual gases. It is easy to modify our mechanical illustration so as to introduce events of this class. It may be done in either of the models we have employed by imagining the surface to be roughened (either by a small amount of friction or in the sense of being covered with slight frictionless elevations and depressions) and by supposing electrons (the charges of electricity which are associated with chemical bonds, and which, so long as they are undisguised, are acted on by the disturbance perpetually going on in the surrounding æther) to be carried about by the internal or B events of the molecule. To complete the picture we may suppose most of these electrons to be so connected with the internal economy of the molecule that they can only perform evolutions that are resolvable into partials that have definite periods.

Before this change the internal events were Ba and Bc events, but, owing to the introduction of the slight roughness, the Bc events have become Bb events ; *i. e.* they have acquired the power of very slowly, and through a great number of collisions, affecting u, v, and w, which are the A events. But even if the roughness be so slight that they require a million of collisions to impart a sensible proportion of their energy to the A events, they will accomplish a protracted task of this kind in about the seventh part of the thousandth of one second, if, as we have supposed, the rapidity of events in our model is as great as it is in gases at atmospheric pressures and temperatures. Now, observations with the phosphoroscope indicate that the persistence of Bb events, when once excited, is in all the observed cases much greater ; so that the outer surfaces of our model molecules should be *very* nearly, though not quite, smooth. Other experiments which are in progress seem to show that, in some instances at least, the energy radiated away from phosphorescent events is much less than that which they lose by conduction, *i. e.* by imparting energy to A or Ba events. Now an excessively small defect in smoothness, such as we have supposed, would not prevent the Boltzmann-Maxwell distribution of energy from being nearly the actual distribution among A and Ba events, wherever the other conditions of the theorem are, or are nearly, fulfilled ; while side by side with them any amount of energy may be maintained in Bb events by the electro-magnetic waves which unremittingly traverse the surrounding æther, or may be set up by chemical reaction.[1]

Another important matter to be referred to is that in the cases in which the theorem holds good, γ, the ratio of the two specific

---

[1] It is easy to contrive other useful models, and to treat them like those in the text. Of this kind are models with spherical, spheroidal, or ellipsoidal outer surfaces, but with centres of inertia, either displaced from the centre of figure, or moving about it under definable conditions ; or with more than one body inside the outer surface, and either concentric or not concentric with it, and with viscous or other connexions which would provide for various kinds of interaction ; or with the rigid outer surface discarded, and central forces put in its place—a substitution which either need not, or need not more than a little, alter the condition that the average energy shall be a sum of squares ; and many others. Each may be in its way instructive if we use it to enable us to picture modes of action that occur in gases, and if we are careful not to be misled into fancying that any of our models can be accepted as even in a remote degree resembling the state of things that does prevail within the molecules of matter.

heats (at constant pressure and at constant volume) has the following value—

$$\gamma = 1 + \frac{2}{m}$$

where m is the number of terms—each the square of a momentoid multiplied by a selected co-efficient — in the expression for the energy. Now observation gives γ in many cases, and we thus arrive, by the foregoing equation, at m, the number of the terms in the expression of T, which is the same as the number of degrees of freedom in the molecule of those events with which the theorem is concerned, if the constitution of the gas be such that the theorem approximately applies to it. To what motions these degrees of freedom are to be supposed to correspond will depend on what experiment has been made use of in determining γ. If the experiment is one that lasts a long time—for instance a whole second or more—then almost the only motions that are concerned are the A and the Ba motions; but if it depends on rapidly changing events, as where the velocity of sound in the gas is the fact that is ascertained, then we may expect that some of the Bb events will also influence the result. It is very convenient to distinguish the internal events into Ba motions and Bb motions; but it must be remembered that this distinction is one of degree, and that, although in most gases they appear as different as is the chin from the cheek, it would nevertheless be quite as impossible to indicate precisely where the one ends and the other begins.

The following Table of the best determinations of γ is given by Mr. Capstick in *Science Progress* for June, 1895. I have added the last two columns in which are given the values of m which the determinations would suggest, if the Boltzmann-Maxwell Theorem could be regarded as holding good for the gas :—

[Table of Cases.

Name of Gas.	Chemical Formula of Molecule.	Atomicity of Molecule.	Observed Value of γ.	Computed Value of	
				m.	$m-3$.
Mercury, ...	Hg	1.	1·67	3·0	0·0
Argon, ...	Not yet known.		1·65	3·1	0·1
Transparent Gases. Hydrogen, . . .	H_2		1·41	4·9	1·9
Nitrogen, . . .	N_2		1·41	4·9	1·9
Carbon monoxide, . .	CO		1·40	5·0	2·0
Hydrochloric acid, . .	HCl		1·39	5·1	2·1
Hydrobromic acid, . .	HBr		1·42	4·8	1·8
Hydriodic acid, . .	HI	2.	1·40	5·0	2·0
Coloured Gases. Chlorine, . . .	Cl_2		1·32	6·2	3·2
Bromine, . . .	Br_2		1·29	6·9	3·9
Iodine, . . .	I_2		1·29	6·9	3·9
Iodine chloride, . .	ICl		1·31	6·5	3·5
Carbon dioxide, . . .	CO_2		1·308	6·5	3·5
Nitrous oxide, . .	N_2O		1·310	6·5	3·5
Sulphuretted hydrogen, .	SH_2	3.	1·340	5·9	2·9
Carbon bisulphide, .	CS_2		1·239	8·4	5·4
Ammonia, ...	NH_3	4.	1·30	6·7	3·7
Methane, ...	CH_4		1·313	6·4	3·4
Methyl chloride, . .	CH_3Cl		1·279	7·2	4·2
Methyl bromide, . .	CH_3Br		1·274	7·3	4·3
Methyl iodide, . .	CH_3I		1·286	7·0	4·0
Methylene chloride, .	CH_2Cl_2	5.	1·219	9·2	6·2
Chloroform, . . .	$CHCl_3$		1·154	13·0	10·0
Carbon tetrachloride, .	CCl_4		1·130	15·4	12·4
Silicon tetrachloride, .	$SiCl_4$		1·129	15·6	12·6
Ethylene, ...	C_2H_4		1·260	7·7	4·7
Vinyl bromide, . .	C_2H_3Br	6.	1·198	10·1	7·1
Ethane, ...	C_2H_6		1·180	11·1	8·1
Ethyl chloride, . .	C_2H_5Cl		1·187	10·7	7·7
Ethyl bromide, . .	C_2H_5Br	8.	1·188	10·6	7·6
Ethylene chloride, .	$C_2H_4Cl_2$		1·137	14·7	11·7
Ethylidene chloride, .	$C_2H_4Cl_2$		1·134	14·9	11·9
Allyl chloride, . .	C_3H_5Cl		1·137	14·7	11·7
Allyl bromide, . .	C_3H_5Br	9.	1·145	13·9	10·9
Alcohol, . . .	C_2H_5OH		1·133	15·1	12·1
Propane, . . .	C_3H_8		1·130	15·4	12·4
Normal propyl chloride, .	C_3H_7Cl		1·126	15·9	12·9
Isopropyl chloride, .	C_3H_7Cl		1·127	15·9	12·9
Isopropyl bromide, .	C_3H_7Br	11.	1·131	15·4	12·4
Ethyl formate, . .	$HCO·OC_2H_5$		1·124	16·1	13·1
Methyl acetate, . .	$CH_3CO·OCH_3$		1·137	14·7	11·7

In this Table, γ is the ratio of the two Specific Heats, as given by observation; m is the number of degrees of freedom of each molecule; and $m-3$ is the number of degrees of freedom of its B, or internal, motions: according to the Boltzmann-Maxwell Theorem.

Postponing for the present the observations which the details of this Table suggest, and taking a general survey of it, it was difficult to see how the small number of degrees of freedom suggested by the Boltzmann-Maxwell Theorem, as shown in the last column of this table, could be reconciled with the known great complexity of the molecules of which real gases consist, until Professor FitzGerald pointed out (Proceedings of the Royal Society, for February 14, 1895, page 312) that the æther, acting on the electrons, which in turn are intimately connected with the ponderable matter of the molecule, must perform the function of a more or less perfect linkage between molecules, compelling them, so far as some of their motions are concerned, to move together in swarms. This follows at once from the circumstance that the electro-magnetic waves, in which radiant heat and light consist, are hundreds of times longer than the average intervals between molecules in gases at the pressures and temperatures at which the gases in the Table were when experimented on to determine the value of γ.

There may be a hundred degrees of freedom in a molecule. Of these the three which are concerned in its power of travelling about between its encounters are not affected by what goes on in the æther, and are therefore inalienably associated with that molecule; but as regards the 97 others, the linkage through the æther may be such that millions of molecules are, as it were, held in one grasp, either firmly or more or less loosely. Accordingly, as regards any one molecule, these 97 may make no appreciable increase, or may make but a moderate increase to the three which in all cases must attach to the molecule. These three are A events, and along with them we should class the few Ba events which have no electrons associated with them, of which there seem to be two in several of the transparent diatomic gases.

We here seem to be led to another conclusion. If the æther were a mere linkage, and not at the same time an agency which excites simultaneous motions within swarms of molecules, it would

appear from the Boltzmann-Maxwell Theorem that none such would in any appreciable degree be brought into existence by the encounters between molecules. If, for example, the expression for T contains two B terms instead of 97, then only $\frac{2}{5}$ of the energy which is taken account of in the theorem, would be available for distribution among 97 distinct kinds of motion, and therefore too little for any but a very few of them to be able to exhibit an observable effect. The rest, the Bb events, would all depend for their activity upon energy reaching the molecules as radiant heat or in some other form through the æther, or in some other way, as, for example, from a disruption of chemical bonds. But though the encounters would be unequal to the task of arousing them from a state of quiescence, they, on their side, if brought into a state of activity by some other agency may be able to impart energy to A and Ba events, which are the proximate dynamical cause of the ordinary gaseous laws. This peculiar behaviour, whereby energy passes more freely one way than in the opposite direction, is a dynamical consequence of the linkage between molecules to which Professor FitzGerald has called attention. Owing to this linkage the encounters may have to produce an effect on a platoon of molecules in order to affect the Bb motions of any one of them; and as these encounters are many and irregular their aggregate effect can be but small wherever the linkage is effective; while, as regards the re-action, the body of linked Bb motions act in each encounter on the A or Ba motions of a single molecule and may produce a considerable effect on them. The dynamical relation is analogous to what would prevail between a number of light pellets bombarding a massive body on all sides. Their effect on the motion of the massive body is small, while its effect on their motions is large. It seems to be in this way that radiant heat can warm a gas through the lines in its spectrum, very slowly in the more transparent gases, less slowly in coloured gases.

An electron within a molecule may be associated with either its Ba or its Bb motions. Thus, when a phosphorescent body has been exposed to suitable light, it is an electron associated with Bb motions that is primarily acted on by the æther. Now, phosphorescence is a very prevalent property of bodies, inasmuch as it has been ascertained by the phosphoroscope that a large proportion of

the substances about us are phosphorescent. And although most of them, after being stimulated, retain their power of radiating light for but the fraction of a second, there are some phosphorescent substances in which it lasts for hours. It must be remembered that any fraction of a second which the phosphoroscope can detect is an immense duration as regards the rapidity of molecular events. Accordingly it is with Bb events that we are here dealing. All Bb events are sluggish from the molecular standpoint in handing over any excess of energy they may possess, either directly or indirectly, to the motions of translation of the molecule. But viewing the matter from our human standpoint it is convenient to distinguish those which can accomplish this in a small fraction of a second from those which take so much longer a time that we can easily perceive it. We may call the first Bb_1 events. These are they which can effect the transfer through some few millions of encounters. And we may call the still more isolated events Bb_2 events. These latter, for example, manifest their existence when phosphorescence lasts for a whole second or more—truly enormous durations as regards molecular activities.

When an electron is associated with Ba events it will promptly transfer over any excess of energy it receives from the æther to u, v, and w, the translational velocities of the molecule. Accordingly, on the one hand, the temperature and pressure of the gas will increase, and on the other, the ætherial undulations that acted on the electron will have ceased—in other words, the gas is one that has an absorption spectrum.

If, at the other extreme, the electron is associated with Bc, or absolutely isolated events, a beam of light passing through the gas will, if it contain certain rays, set these electrons moving. They, however, will not impart any of their acquired energy to other events going on in the gas, but will continue swinging in all the molecules in coincidence with the electro-magnetic wave as it sweeps past them in the æther; thus restoring to the latter the same amount of energy which they received, and in the form of an undulation travelling at the same rate, and in the same direction, and oscillating in the same periodic time. Thus, so far as regards the motion of this electron, the gas is transparent.

Between these extremes, electrons associated with Bb events will lie, and may produce any intermediate event.

It is very instructive to glance over the determinations of γ in the Table on p. 364. Take, for example, the diatomic gases. Six of them are transparent, and the other four are coloured. The transparent gases furnish values for γ, which all lie in the neighbourhood of 1·4, which is the value which would correspond to a molecule having five degrees of freedom if the conditions of Boltzmann's theorem were completely fulfilled. In transparent gases they are probably not much interfered with, since in them the electrons are associated with Bb_2 events, and it is only after *many* millions of encounters that the æther can, through them, sensibly effect the A and Ba events with which the theorem is concerned. On the other hand, in the coloured gases one or more electrons (in these special gases probably something like six or eight electrons, judging from their spectra) are associated with Bb_1 events, and largely affect the events with which the theorem is concerned. They, accordingly, cause γ to be different from what it would be if the dynamical interactions stood alone, which, judging from the transparent gases, we may conclude would be 1·4, furnished by 5 degrees of freedom. The Bb motions in question would probably add something like three times 6 or 8 more degrees of freedom if the molecule stood alone, but by reason of the linkage only some fraction of this addition has to be made. It appears from the Table that in chlorine, which is the least deeply-coloured gas, that is, the gas in which the linkage is most effective, the addition to be made is of 1·2 degrees of freedom; while in bromine and iodine an addition of 1·9 degrees of freedom has to be made, indicating that the linkage is more lax in these gases.

Since in so many bodies the electrons seem to be associated with events which are very much isolated from those that are chiefly affected by the encounters, the modification of the dynamical condition which is introduced through them may be regarded as a perturbation. It would perhaps not be impracticable to discover in what way perturbating forces, not obeying the conditions of the Boltzmann-Maxwell theorem, can influence the results of that theorem. This would be of much value; and, if it can be made out, will, perhaps, explain why, in some transparent diatomic gases, the value of γ is above 1·4, while it is less than that value in others. The reason probably is that in hydrogen,

nitrogen, and hydrobromic acid the motions associated with their two Ba degrees of freedom are able to rouse a certain amount of activity in adjoining Bb events, and that thus a part of their energy gets to be exposed to linkage.

Hitherto we have regarded molecules as acted on in two ways only—by dynamical interactions between or within the molecules, and by the effect of electro-magnetic waves on such of the electrons as are undisguised charges of electricity. But there are other ways in which molecules may be acted on, of which the most conspicuous intervenes energetically on those critical occasions when chemical reaction takes place. Here it is the electrons that are primarily concerned, as is manifest from Faraday's law of electrolysis. In cases of friction also, or of disruption of a crystal, it is manifest that some of the electrons are started into activity. In fact it may be presumed that the intermolecular bonds within a crystal are fundamentally of the same kind as the interatomic bonds within a molecule, and that in both it is interaction between electrons that is primarily called into play. It should also be noted that the number of electrons within an atom may be greater than its place in Mendeléeff's Table would seem to suggest, as is, for example, evidenced by the chemical behaviour of potassium.

In chemical reactions, if the product is gaseous, and if the electrons which are set swinging are associated with Ba events, the most obvious effect is a sudden increase of temperature and pressure; if associated with Bb_2 events the most obvious effect is a flash of light; and if associated with Bb_1 events both effects will be conspicuous : and this, in accordance with what we learn through the phosphoroscope, would seem to be what most frequently happens.

It seems probable that it is when excited by chemical reactions that electrons produce their most conspicuous luminous effects, whether in flames or in so-called incandescent spectra. It should be remembered that as electrons are for the most part associated with Bb motions within the molecule, it may happen that they but slowly influence the temperature of the gas as indicated by the thermometer, and that accordingly the luminous effects may be greatly in excess of what a mere incandescent body at the same moderate temperature could produce. Hence the phrase incandescent spectrum is not always appropriate, since the supposition

that the temperature inside a Plücker tube must be high is erroneous.

These inferences are entirely borne out by the recently published observations of Professor Lewes upon gas flames (see Proceedings of the Royal Society for March 7 and March 21, 1895). He finds that the first group of chemical changes which the issuing gas undergoes are brought about by *radiant* heat; in other words, by electro-magnetic waves in the æther acting on those electrons which are concerned in the chemical changes, and which, from their not being affected by convected heat, must be associated with Bb, and not with Ba events. In this way

$$H \cdot C \vdots C \cdot H \qquad \begin{matrix} H \cdot \\ H \cdot \end{matrix} C \begin{matrix} \cdot H \\ \cdot H \end{matrix} \quad \text{and } H \cdot H$$

<div align="center">acetylene,   methane,   hydrogen</div>
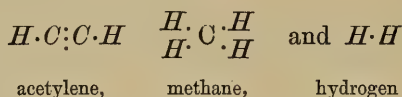
are produced. Of these, acetylene is the one that, on decomposition, emits almost all the light. Professor Lewes finds that, on attaining a situation where the temperature is sufficient, the acetylene resolves into carbon and hydrogen, which subsequently combine with oxygen; and that in the brief interval one or both of them emit *more light than belongs to the temperature of that situation*; in other words, that one or more electrons associated with Bb motions have been roused into great activity by the decomposition, and have time to radiate abundantly, probably a long time from the molecular standpoint, before either they have expended their excess of energy, or the combination with oxygen takes place, whichever event comes first.

The summary of the results of this recent investigation have been here translated into molecular language, to serve as an example of the additional insight which we may already hope to gain into the chemistry of nature by adopting the molecular standpoint; and whenever the secret of the motions of electrons within molecules becomes known, this insight will doubtless be vastly increased. Through the spectroscope we seem to be on the borderland of this great discovery.

Reference has been made to chemical reaction, friction, and the disruption of a crystal, as events which may bring into a state of activity some of the electrons associated with Bb motions. Another event which seems to have this effect is the gaseous

encounter between two molecules of the same kind. A suggestive experiment was made in the laboratory of the Royal Dublin Society, when Professor Emerson Reynolds, F.R.S., and the present author were engaged in examining the spectra of coloured vapours ("Philosophical Magazine," July, 1871, p. 41). We had examined the splendid absorption spectrum of chlorochromic anhydride mixed with air. Here the encounters that the molecules of the vapour met with were most of them encounters with molecules of air, the minority only being encounters between molecules of the vapour. If the vessel containing the vapour be freed from air, the encounters between molecules of the vapour will be present in the same number as before, while all encounters between air and vapour will be absent. Hence we argued (for at that time we supposed the motions in the molecules to have been evoked by the undulation in the æther),[1] that the molecules being less knocked about should produce a spectrum of lines that would be less diffuse. On trying the experiment, however, we found that the spectrum was sensibly the same as before. From this observation it would appear that the motions to which the spectrum is due are excited by the encounters between molecules of the vapour, and are uninfluenced by encounters between air molecules and vapour molecules. Hence they are due to something different from the mere kinetic energy of the collisions; and this something may be, and probably is, that during the struggle between molecules of the same kind, a struggle which is a protracted struggle from the molecular standpoint, there occurs either always, or now and then, an interchange of some of the chemical atoms constituting the molecules. This, which is equivalent to two chemical decompositions, followed by two equivalent chemical combinations, must set the electrons concerned into a state of more or less activity.

---

[1] The amplitude of the Bb motions which the undulation in the æther, if acting alone, can develop is apparently too small; and this is probably because, at this small amplitude, the transference of energy from Bb motions to Ba and A motions is inconspicuous. Where this is the case the ætherial undulation acting alone upon the gas cannot suffer any sensible amount of absorption. But the conditions are altogether different if some other agency produces an amplitude which can freely part with its energy by conduction, and which at the same time can be acted on by the æther in the direction which tends to keep the amplitude up. Under these circumstances there will be active withdrawal of energy from the æther, and an absorption spectrum will result. This seems to be what happens in coloured gases.

This interchange of atoms during the encounters is presumably the source, not only of such absorption spectra as that of chloro-chromic anhydride, but also of the bright spectra seen in Plücker's tubes.

If the gas be monatomic the spectrum is probably emitted only when the circumstances are such that two molecules can tempo-rarily coalesce into a diatomic molecule during the encounter, and become dissociated when the encounter is over; but in all cases where there is no ultimate change in the chemical constitution of the gas, its spectrum seems to be due to some event which is equi-valent to equal and opposite chemical reactions having taken place during either all or some of the encounters.

An excellent way of helping us to appreciate the events with which we have to deal in molecular physics, is to conceive a model of them in which the durations shall all be enlarged 600 billions of times (6×10^{14}). This particular magnification is found to have special convenience attached to it.[1] If prolonged to this extent, the most rapidly recurring motions in nature that are *as yet* known to us, viz.: those periodic events in a gas which give rise to the lines in its spectrum, would swing at rates comparable with the motions of the limbs of animals, and would have about as great a range from the swiftest of them to the slowest. On the same immense time-scale the duration of the journeys of the molecules of ordinary air would average about one day each, while the encounter which closes each journey may last some 20 minutes.[2] The motions of the limbs of animals are able to accom-plish a good deal in a struggle lasting 20 minutes. On the same

---

[1] Wave-lengths of rays of light are usually expressed as fractions of a micron, and pendulums beating the same fractions of a second represent the corresponding ætherial vibrations on the scale employed in the text.

[2] We may fill in this picture by combining a lengthening of distances with the prolongation of the times. A cubic millimetre, the volume of a small pin's head, if each of its edges were magnified 10^{10} times, would become almost as huge as the earth. Under the same circumstances molecules of air would be spaced at intervals averaging ten metres; and 700 metres would have become the mean distance to which they would travel between their encounters. On this great scale, it would not be inappro-priate to use men or other animals to represent the individual molecules—their hearts beating, their chests heaving, their limbs in vigorous motion to represent the *B* or internal events; and as to the motions with which the molecules of a gas dart about amongst one another, these as they exist in common air would have become journeys as long and of as various lengths as the streets of a great city, while the widths of the

scale, the ten-thousandth of a second of time grows to be an immense duration, extending to 1900 years. The number of struggles to be encountered by each molecule in the ten-thousandth of a second, is accordingly the same as the number of days in the whole Christian Era, from the birth of Christ down to the end of the present century. If something can be done during the 20 minutes that one of the struggles may last, how great a task might be accomplished by such an enormous succession of them. It must be borne in mind, too, that these encounters are not mere repetitions of one another, but that each has its own definite inci-dents. Moreover, all this is what occurs in the experience of one individual molecule, so that we must multiply it by something like a thousand millions, in order to sum up what may be accom-plished by all the encounters of all the molecules within one cubic micron[1] of gas in the ten-thousandth part of a second, and that we may in some degree understand how it comes to pass that oppor-tunity is afforded in nature for accomplishing work which requires rare collocations of conditions that can but seldom emerge. Such is Nature's real laboratory—events in inconceivable numbers, the whole phantasmagoria of these innumerable events changing every instant down to its minutest details with inconceivable rapidity, the changes in most cases kept within limits, but in some exploring every part of a wide range : it is thus that those wonderful opera-tions are carried on, which issue in the astonishing results that lie everywhere in such profusion around us. We seem almost to get an obscure and partial glimpse of how, in organic nature, tasks of the most unlikely kind are accomplished, through the needful

streets may stand for the intervals at which the representatives of the molecules are to be spaced asunder at starting.

In this model we have applied so much more magnification to time than to space, that all the velocities come out 60,000 times slower than in nature. Accordingly our animated molecules must be conceived of as quietly gliding along the journeys they have to make between their encounters ; for the mean duration of a journey is to be a day, and the average speed must accordingly be only half a metre per minute— on the supposition that our model is to represent what occurs in gas as dense as air and at its temperature and pressure.

A model of this kind is not without its use, if it were only as a means by which we can gain a lively perception of how considerable the events going on *within* the mole-cules may be when compared with the motions of translation of the molecules.

[1] There are 70 or 80 cubic microns in the volume of each of the small disks in human blood.

opportunities now and then turning up within each tiny speck of so Protean a material as protoplasm, a body of which the mutations have probably time-relations of the same order as those we have been endeavouring to illustrate, and whose activities are therefore more incessant, more various, and more complex, within every thousandth of a second, in every speck and corner of each living cell, than the mind can even conceive. It is very little man yet knows of what is going on abundantly about him in every stick and stone.
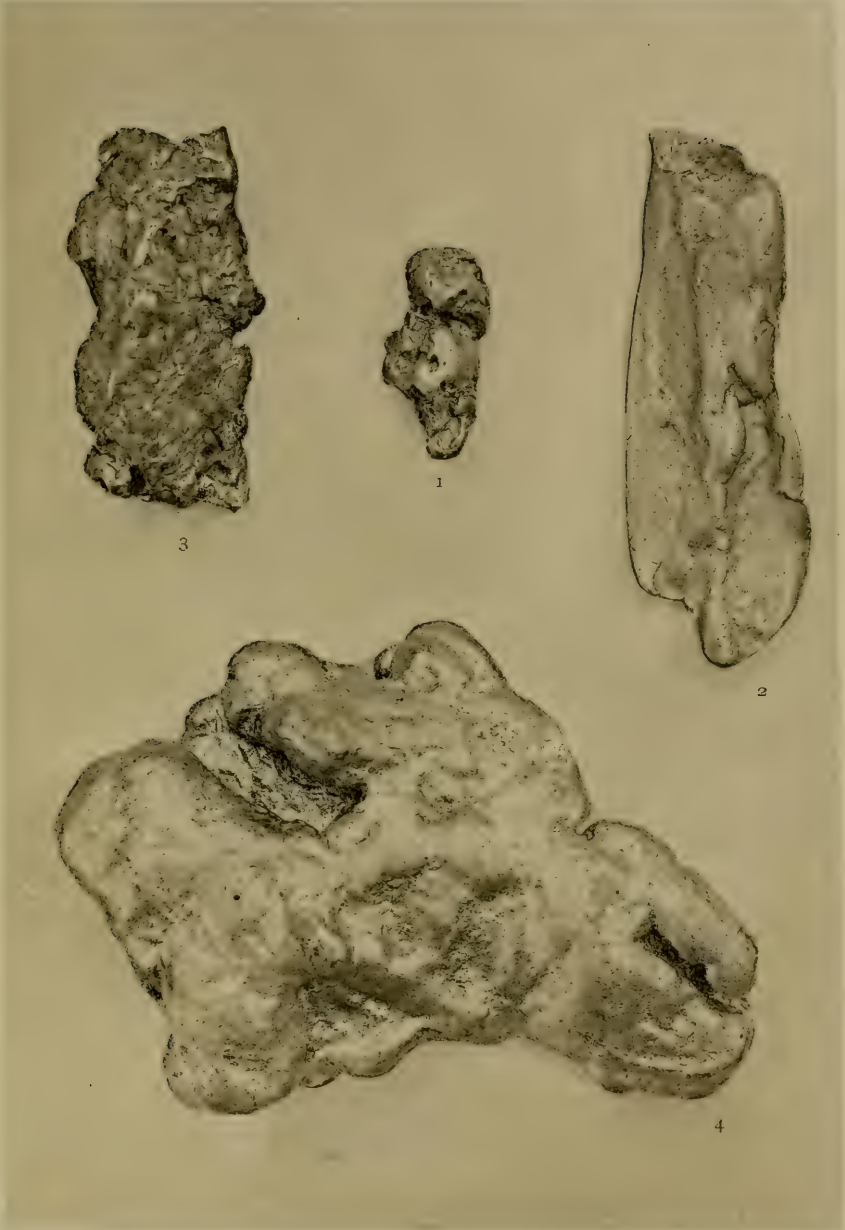
GOLD NUGGETS FROM CO. WICKLOW

(*Natural size*)

Plate XIV.
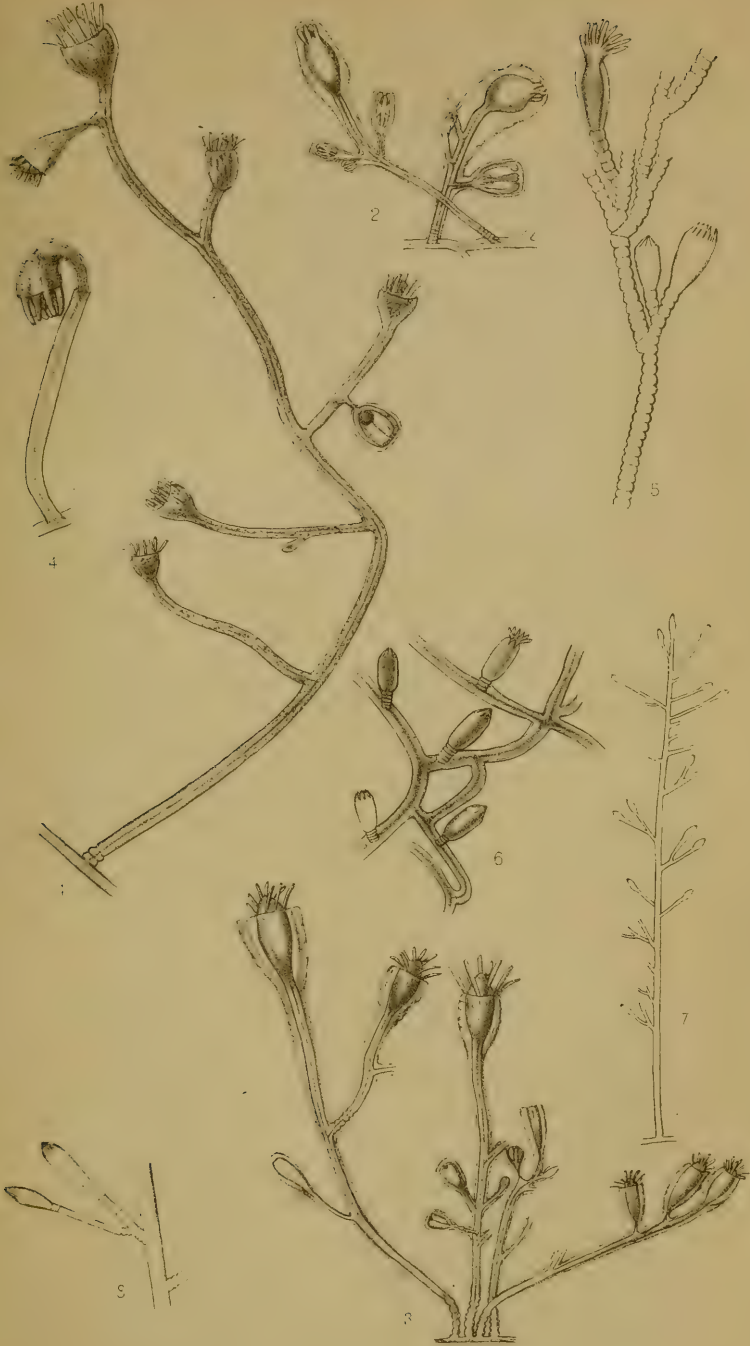
HYDROIDA.

THE

SCIENTIFIC PROCEEDINGS

ROYAL DUBLIN SOCIETY.

CONTENTS.

The Authors alone are responsible for all Opinions expressed in their Communications.

Royal Dublin Society.

FOUNDED, A.D. 1731.   INCORPORATED, 1749.

EVENING SCIENTIFIC MEETINGS.

THE Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and ready for transmission to the Editor.

XLVI.

SOME REMARKS ON DIFFICULTIES OF MERIDIAN CIRCLE WORK. By ARTHUR E. LYSTER, M.A.

THE author gave a general description of the meridian circle and its use, recommending the adoption of the late Dr. Romney Robinson's device for preventing the growth of fungus on the spider lines by the substitution, when the telescope was not in actual use, of a cylinder containing drying materials for the draw-tube of the eye-piece; and noticing that, in the use of the ordinary mercury pan reflector without amalgamated copper plate, for the determination of collimation correction and nadir point, he had obtained improved steadiness of the reflected image by the careful protection of the reflecting surface from currents of air.

In illustration of Chauvenet's remarks on the importance of having the whole divided circle at a uniform temperature, he submitted a discussion of a conceivable simple distribution of temperature as follows:—Consider a vertical uniform circular disc, and suppose that when it is at a uniform temperature, a microscope is placed so as to read an angle 45° above the horizontal diameter. Now, let each element of the disc experience a fall of temperature proportional to its distance from the horizontal line. The fall of temperature at the top of the vertical diameter being t_0, and suppose the temperature of the lower half of the disc to rise according to the same law: then if x and y are the co-ordinates of any point of the disc, and the fall of temperature at this point be t; and if x' and y' are the new co-ordinates,

$$dx' = (1 - at)dx; \quad dy' = (1 - at)dy; \quad t = yt_0;$$
$$\therefore x' = x - at_0xy; \quad y' = y - \tfrac{1}{2}at_0y^2; \quad \text{also } x^2 + y^2 = 1;$$

the elimination of x and y between these three equations would give the equation of the new boundary of the disc.

Considering the point whose initial co-ordinates were $x = y = \dfrac{1}{\sqrt{2}}$,

the new co-ordinates are $x' = \dfrac{1}{\sqrt{2}} - \dfrac{at_0}{2}, \quad y' = \dfrac{1}{\sqrt{2}} - \dfrac{at_0}{4}$,

so that, if $45° + \theta$ be the angle which the line joining the new

position $x'\, y'$ makes with the horizon, $\theta = \dfrac{at_0}{4\sqrt{2}}$ which, taking $t_0 = 1$,

$a = 0\cdot000018$, gives $\theta = 0''\cdot66$ approximately.

Thus, it being assumed that the horizontal diameter of uniform temperature has remained fixed in position, the microscope, which initially read 45°, would, with the altered temperature, read the position as being about $\frac{2}{3}$ of a second of arc less, and the discrepancy would be increased if, as is conceivable, the horizontal diameter, instead of remaining a straight line, bent upwards at each end.

The author noticed that, with the simple law assumed, the error would be eliminated by the mean of the four microscopes; and that when working at Dunsink, when the nights were much colder than the days, he had usually found a small alteration in the nadir point and equator point readings of the circle as the night progressed, amounting sometimes, between the commencement and ending of work, to as much as $2''$ of arc, which he attributed to differences of temperature of the divided circle; one part of the circle, about a quadrant, being subjected to the radiation of the naked pier, which was usually warmer than the night air circulating about the instrument. He thought it would be desirable from time to time to apply some delicate temperature measurer, such as a thermopile, to the different parts of the circle, so that materials could be collected for an investigation of the matter. The mere collection of micrometer readings at different times, without any information as to the distribution of temperature, being manifestly insufficient for the purpose. He was gratified to learn that the provision of a papier-maché screen to protect the circle was contemplated at Dunsink.

XLVII.

A METHOD OF USING COMMON PETROLEUM AS THE
ILLUMINANT FOR BEACONS AND BUOYS BY WHICH
A CONTINUOUS LIGHT MAY BE MAINTAINED, DAY
AND NIGHT, FOR WEEKS OR MONTHS, WITHOUT
THE NECESSITY FOR THE ATTENDANCE OF A
LIGHT-KEEPER. By JOHN R. WIGHAM, M. R. I. A.,
Member of the Council of the Royal Dublin Society.

THE placing of lights on the beacons and buoys which mark the
rocks and the shoals of our navigable rivers and estuaries, and
show the safe channels by which these dangers may be avoided, is
becoming an important branch of the system of general coast
illumination of every civilized country, and is increasingly claim-
ing the attention of Harbour Boards and Nautical Authorities.

The lights for such purposes do not need to be of high illumi-
nating power, not requiring to be seen from a great distance, but
the isolated positions in which they have to be placed, and the
impossibility of providing for them the attendance of light-keepers,
make it imperative that these lights should be so constructed that
they will continue to burn without any such attendance for long
periods, say for weeks or months, as may be required by the
difficulty of access or otherwise.

Hitherto buoys and isolated, or partially isolated, beacons have
generally been illuminated by compressed oil-gas which is capable
of maintaining the light for a considerable period of time, and when
the compressed gas is exhausted, a further supply is brought along-
side, by boat or steam tender, and the empty receiver of the beacon
or buoy is replenished, the new supply of gas being brought to
it from a special gas making establishment on shore. All this
renders the illumination of the buoy or beacon by compressed gas
expensive and troublesome and a less expensive and simpler plan,
such as that about to be described, very desirable.

At first sight it may appear a very easy thing to keep a lamp burning for any length of time by what would seem the obvious expedient of giving it a sufficient and continuous supply of oil; but if anyone will try the experiment, he will find that at the end of a few days the wick will have become so charred as to obstruct the capillary attraction which brings the oil to the point of combustion, and the light will go out.

A carbonised wick has been devised, of which a sample was shown, which lasts longer than an ordinary wick, but even with that wick the deposit from the oil after some days' burning is sufficient to extinguish the light.

It occurred to me that if it were possible to cause the wick to move so that the same part of it would not be constantly exposed to the action of the heat of the combustion this difficulty would be got over, and a continuous light secured. I tried many plans to this end; some of them, though successful, were complicated and expensive. I therefore abandoned them, and at last hit upon the method described in the present Paper.

In an ordinary paraffin burner, the wick, as we all know, is perpendicular to the level of the oil in the oil container and draws its oil vertically from it, but a wick applied in this way could not readily be made to alter its position automatically as its combustion proceeded. I therefore devised the plan of burning the wick horizontally, passing it slowly over a small roller, thus obtaining the light from the side and not from the end of the wick.

The experimental apparatus by which this plan was worked out was exhibited and explained, and it was seen at a glance how the wick was used.

Fig. 1.

The drawing (fig. 1), shows the form of the lamp as it is used in practice. A fountain supplies the lamp with a sufficient supply of oil at a uniform level for the
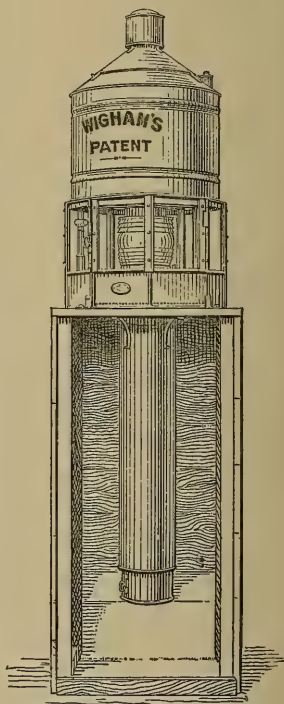
time during which the lamp is to be maintained (in the case of this particular lamp thirty-one days). It is constructed on the bird-cage fountain principle, and has a cock, or valve, to enable the oil to be cut off whenever necessary. The lamp receives oil from the above fountain as it is required for the maintenance of the light. The wick is passed over a roller which is surmounted by a combustion cone and surrounded by lenticular apparatus; one end of the wick being conveyed up in an oil-tight tube, with holes in its sides as it passes through the body of the lamp, and the other passing down through a tube standing above the level of the oil in the lamp and soldered or secured at the lower end. A circular float is placed in a cylindrical tank fixed to the bottom of the lamp and filled with oil. When the lamp is first lighted, this float is at the top of the tank and is attached by means of hooks or loops to the wick. The oil from the tank is permitted to drop through a valve or cock supplied with a cotton core through which, drop by drop, at such speed as may be necessary, the oil descends into the receiver, bringing with it the float and the wick which is attached to it. When, at the end of a month or such other period as may be desired, it is necessary to replenish the lamp with oil, the receiver is emptied and the fountain and tank refilled.

Buoys.—Such a lamp as fig. 1 is suitable for permanent beacons or perches, but when a light on this principle is required for *buoys* a smaller lamp is used, and the supply of oil, instead of being overhead as in the beacon lamp, is underneath the burner. This arrangement is adopted mainly to keep the centre of gravity low. In the case of buoys it is necessary to fix the lamp upon swivels or gimballs, so that however great may be the motion of the sea, the lamp may be kept practically level. Arrangements are also made by divisions in the oil-chamber by which, when it is for a moment brought out of level by the motion of the sea, the oil is prevented from flooding the wick, because of its having but slow access to it during the time of the passing of the wave, after which its proper level is again maintained.

A full-sized working example of this lighted buoy lamp, with gimball arrangement, by which it may be kept practically level, was exhibited, and is shown in fig. 2.

There is a well-known class of buoy called the Courtenay automatic whistling buoy in which the motion of the sea sounds a powerful whistle or horn and thus assists mariners by sound as well as by sight, but, inasmuch as these buoys are only visible by day, it is satisfactory to know that the plan of lighting we are now considering can be easily applied to them, so that by night as well as by day they may be useful warnings to the sailor.   A simple adaptation of the Courtenay buoy enables this to be done.   The air tube which sounds the whistle is turned at right angles to the vertical section of the buoy, and the centre of the buoy is thus made available for the cylindric tank of the burner.

Cost.—We come now to the important question of cost.

Fig. 2.

The cost of this system of lighting beacons and buoys is very trifling, the consumption of oil being only half a gallon in twenty-four hours.   This at the present price of oil, say 6*d.* per gallon, is only 3*d.* per day of twenty-four hours. This expenditure of oil is inclusive of what may appear at first sight to be the waste of oil in the constant drip, which as you have seen, takes place from the lower receiver of the lamp.   This so-called waste is, however, of great value in calming the sea in the neighbourhood of the buoy or beacon.   It is extraordinary to how great an extent a single drop of oil will spread itself over the sea, smoothing what would otherwise be broken water; but if desirable to reduce the above cost of 3*d.* per day still further, this drip of oil, instead of being allowed to drop into the sea, can be collected by the use of the receiver shown in the drawing, and thus be available for use again, in which case the 3*d.* per day would be reduced by 2*d.*, leaving the total cost only 1*d.* per day.

I think it is evident that the economy of this plan as compared with the compressed gas system is very great, and that the action of the lamp is so simple as to be of easy application.
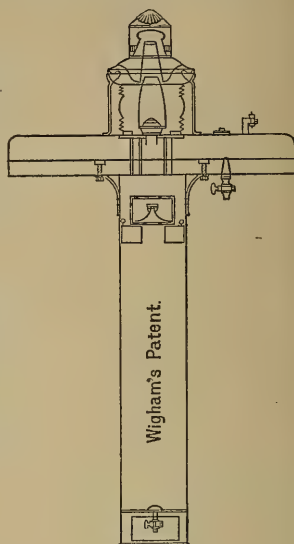
XLVIII.

ON HAMILTON'S SINGULAR POINTS AND PLANES ON FRESNEL'S WAVE SURFACE. By PROFESSOR WILLIAM BOOTH, M.A., Hoogly College, Bengal.

THE equation of the surface is

$$W \equiv (a^2x^2 + b^2y^2 + c^2z^2)(x^2 + y^2 + z^2) - a^2(b^2 + c^2)x^2 - b^2(c^2 + a^2)y^2 \\ - c^2(a^2 + b^2)z^2 + a^2b^2c^2 = 0,$$

and, by common algebra, this equation may be written in the form

$$P^2 + l_1 l_2 l_3 l_4 = 0,$$

where P stands for

$$a^2x^2 + b^2y^2 + c^2z^2 + b^2(x^2 + y^2 + z^2) - b^2(c^2 + a^2),$$

and $\qquad l_1$ for $\quad x\sqrt{a^2-b^2} + z\sqrt{b^2-c^2} + b\sqrt{a^2-c^2},$

$\qquad\qquad l_2$ for $\quad x\sqrt{a^2-b^2} - z\sqrt{b^2-c^2} + b\sqrt{a^2-c^2},$

$\qquad\qquad l_3$ for $\quad x\sqrt{a^2-b^2} + z\sqrt{b^2-c^2} - b\sqrt{a^2-c^2},$

and $\qquad l_4$ for $-x\sqrt{a^2-b^2} + z\sqrt{b^2-c^2} + b\sqrt{a^2-c^2};$

hence, it follows at sight, that the plane $l_1 = 0$ meets the surface in a conic,[1] and touches the surface all along this conic, or else the

---

[1] The perpendicular from the origin on the plane $l_1 = 0$ is b, and the perpendicular on the parallel tangent plane to $P = 0$ is

$$\sqrt{\frac{2b^4(c^2 + a^2)}{(a^2 + b^2)(b^2 + c^2)}};$$

the difference of the squares of these perpendiculars, the latter being the greater, is

$$\frac{b^2(a^2 - b^2)(b^2 - c^2)}{(a^2 + b^2)(b^2 + c^2)},$$

which shows the conic is real, as $\quad a > b > c.$

conic is a double line on the surface. The latter case is impossible, for the well-known trace of the surface on the plane $y = 0$ shows no double points where the plane $l_1 = 0$ meets $y = 0$; hence the plane $l_1 = 0$ touches the surface. Again, the ellipsoid $P = 0$ and the ellipsoid of elasticity have manifestly the same planes of circular section, and therefore

$$l_1 = 0, \quad l_2 = 0, \quad l_3 = 0, \quad l_4 = 0$$

are four planes of circular section of the ellipsoid $P = 0$. This proves one of Hamilton's theorems; but it appears that these four circles all lie on one ellipsoid, and assuming for a moment that the reciprocal of the wave surface is the wave surface of

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} - 1 = 0$$

(the sphere of reciprocation being $x^2 + y^2 + z^2 - 1 = 0$); then, by reciprocation, it appears that the wave surface has four conical points, the tangent cones at which all envelop one ellipsoid whose equation is

$$\frac{x^2}{c^2 (a^2 + b^2)} + \frac{y^2}{2a^2c^2} + \frac{z^2}{a^2 (b^2 + c^2)} - \frac{1}{c^2 + a^2} = 0,$$

as I shall show later on.

The reader will have no difficulty in remembering the value of P if he recollects that P is the quadric factor of $\dfrac{dW}{dy}$.

Similarly the equation may be written

$$Q^2 + m_1 m_2 m_3 m_4 = 0,$$

where Q stands for

$$a^2 x^2 + b^2 y^2 + c^2 z^2 + c^2 (x^2 + y^2 + z^2) - c^2 (a^2 + b^2),$$

and m_1 is

$$x \sqrt{a^2 - c^2} + y \sqrt{c^2 - b^2} + c \sqrt{a^2 - b^2}.$$

It is not necessary to write down the values of m_2, m_3, m_4. It may be noted that all the imaginary sections in this case lie on the real ellipsoid $Q = 0$.

Similarly, the equation may be written

$$R^2 + n_1 n_2 n_3 n_4 = 0,$$

where R stands for

$$a^2 x^2 + b^2 y^2 + c^2 z^2 + a^2 (x^2 + y^2 + z^2) - a^2 (b^2 + c^2),$$

and n_1 for

$$z \sqrt{c^2 - a^2} + y \sqrt{a^2 - b^2} + a \sqrt{c^2 - b^2},$$

with corresponding values for n_2, n_3, n_4. In short, Q is the quadric factor of $\dfrac{dW}{dz}$, and R of $\dfrac{dW}{dx}$.

Once more the equation may be written

$$S^2 + p_1 p_2 p_3 p_4 = 0,$$

where S stands for

$$a^2 (b^2 + c^2) x^2 + b^2 (c^2 + a^2) y^2 + c^2 (a^2 + b^2) z^2 - 2a^2 b^2 c^2,$$

and p_1 for

$$xa \sqrt{b^2 - c^2} + yb \sqrt{c^2 - a^2} + zc \sqrt{a^2 - b^2},$$

with corresponding values for p_2, p_3, p_4. If we omit the terms in W of the fourth degree in x, y, z, then the remainder is nearly the value of S with the sign changed. In short, if we had four variables, x, y, z, w in W so as to make it homogeneous in these variables, then S is a factor of $\dfrac{dW}{dw}$.

It is considered important by some writers on Physical Optics[1] to determine the equation of the cone whose vertex is the centre of the ellipsoid of elasticity, and whose base is one of the circles in the case

$$P^2 + l_1 l_2 l_3 l_4 = 0.$$

Its equation is, by the foregoing principles, written down thus:

$$\left[a^2 x^2 + b^2 y^2 + c^2 z^2 + b^2 (x^2 + y^2 + z^2)\right] b^2 (a^2 - c^2)$$
$$= (x \sqrt{a^2 - b^2} + z \sqrt{b^2 - c^2})^2 b^2 (c^2 + a^2) ;$$

on simplification, this becomes

$$a^2 (b^2 - c^2) x^2 + b^2 (a^2 - c^2) y^2 + c^2 (a^2 - b^2) z^2$$
$$- xz (c^2 + a^2) \sqrt{(a^2 - b^2)(b^2 - c^2)} = 0.$$

---

[1] See Bassett, *Physical Optics*, Art. 116, p. 123.

I may remark that these four circles treated in this way only produce two cones, as $l_1 = 0$ and $l_3 = 0$ produce the same cone, so likewise do l_2 and l_4.

I shall now make a few remarks on a specially restricted system of tangential coordinates. Considering λ, μ, ν as the parameters of the variable plane

$$\lambda x + \mu y + \nu z - 1 = 0,$$

it is required to find the relation between λ, μ, ν, which subsists when the plane passes through the pole of

$$Ax + By + Cz + D = 0$$

with respect to the sphere

$$x^2 + y^2 + z^2 - 1 = 0.$$

Now, if this point be $x'y'z'$, we must have

$$\lambda x' + \mu y' + \nu z' - 1 = 0 ;$$

also, we must have

$$x' = -\frac{A}{D}, \quad y' = -\frac{B}{D}, \quad z' = -\frac{C}{D};$$

therefore

$$A\lambda + B\mu + C\nu + D = 0$$

is the required condition, and it is called, in tangential coordinates, the equation of the pole of

$$Ax + By + Cz + D = 0$$

with respect to the sphere

$$x^2 + y^2 + z^2 - 1 = 0.$$

Similarly,

$$a\lambda^2 + 2h\lambda\mu + b\mu^2 + 2g\lambda\nu + 2f\mu\nu + c\nu^2$$
$$+ 2l\lambda + 2m\mu + 2n\nu + d = 0$$

is the tangential equation of the reciprocal of

$$ax^2 + 2hxy + by^2 + 2gxz + 2fyz + cz^2$$
$$+ 2lx + 2my + 2nz + d = 0.$$

Now, since the wave surface is known to be the envelope of the plane

$$\lambda x + \mu y + \nu z = v,$$

where

$$\frac{\lambda^2}{v^2 - a^2} + \frac{\mu^2}{v^2 - b^2} + \frac{\nu^2}{v^2 - c^2} = 0,$$

and

$$\lambda^2 + \mu^2 + \nu^2 = 1,$$

it follows at once that the locus of the foot of the perpendicular from the origin on a tangent plane to the wave surface is

$$\frac{x^2}{x^2 + y^2 + z^2 - a^2} + \frac{y^2}{x^2 + y^2 + z^2 - b^2} + \frac{z^2}{x^2 + y^2 + z^2 - c^2} = 0 ;$$

and as the inverse of this latter surface with respect to the sphere

$$x^2 + y^2 + z^2 - 1 = 0$$

is the reciprocal of the wave surface, its equation is therefore

$$\frac{x^2}{a^2 (x^2 + y^2 + z^2) - 1} + \frac{y^2}{b^2 (x^2 + y^2 + z^2) - 1} + \frac{z^2}{c^2 (x^2 + y^2 + z^2) - 1} = 0 ;$$

but this is the wave surface of the reciprocal of the ellipsoid of elasticity. In other words, " the reciprocal of the wave surface is the wave surface of the reciprocal of the ellipsoid of elasticity." [1]

Now, the equation of the wave surface for the ellipsoid

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} - 1 = 0$$

must be, by the foregoing,

$$T^2 + \nu_1 \nu_2 \nu_3 \nu_4 = 0,$$

where T stands for

$$x^2 c^2 (a^2 + b^2) + 2 a^2 c^2 y^2 + z^2 a^2 (b^2 + c^2) - (a^2 + c^2),$$

and ν_1 for

$$c x \sqrt{a^2 - b^2} + 2a \sqrt{b^2 - c^2} + \sqrt{a^2 - c^2},$$

with corresponding values for $\nu_2 \nu_3 \nu_4$; hence the equation in tangential coordinates of the wave surface of

$$a^2 x^2 + b^2 y^2 + c^2 z^2 - 1 = 0$$

is

$$\varpi^2 + \lambda_1 \lambda_2 \lambda_3 \lambda_4 = 0,$$

where ϖ stands for

$$\lambda^2 c^2 (a^2 + b^2) + 2 \mu^2 a^2 c^2 + \nu^2 a^2 (b^2 + c^2) - (a^2 + c^2),$$

and λ_1 for

$$\lambda c \sqrt{a^2 - b^2} + \nu a \sqrt{b^2 - c^2} + \sqrt{a^2 - c^2},$$

with corresponding values for $\lambda_2, \lambda_3, \lambda_4$. This mode of writing its equation shows that

$$\lambda_1 = 0, \quad \lambda_2 = 0, \quad \lambda_3 = 0, \quad \lambda_4 = 0$$

[1] See Salmon's *Surfaces*, page 426.

are four points on the surface, tangent cones from which all envelop the surface whose equation in tangential coordinates is $\varpi = 0$ (the existence of an infinite number of double tangent planes all passing through a point outside the surface is excluded, as we saw that its reciprocal has not an infinite number of double points all lying on a plane), and the equation in Cartesian coordinates of the surface represented by $\varpi = 0$ is

$$\frac{x^2}{c^2(a^2+b^2)} + \frac{y^2}{2a^2c^2} + \frac{z^2}{a^2(b^2+c^2)} - \frac{1}{c^2+a^2} = 0,$$

as stated above.

It now appears that the equation of the surface may be written in tangential coordinates in three other ways, showing the existence of the twelve imaginary conical points. I shall notice one case only, namely,

$$\sigma^2 + \rho_1 \rho_2 \rho_3 \rho_4 = 0,$$

where σ stands for

$$(b^2+c^2)\lambda^2 + (c^2+a^2)\mu^2 + (a^2+b^2)\nu^2 - 2.$$

This is obtained from the value of S of the reciprocal surface just as ϖ was obtained from the value of P of the reciprocal; similarly the values of Q and R for the reciprocal would furnish the values of the enveloped ellipsoid in the two cases which I have omitted. Also, ρ_1 stands for

$$\lambda\sqrt{b^2-c^2} + \mu\sqrt{c^2-a^2} + \nu\sqrt{a^2-b^2}.$$

This is the case where the four conical (imaginary) points are at infinity, and the tangential equations of these points are

$$\rho_1 = 0, \quad \rho_2 = 0, \quad \rho_3 = 0, \quad \rho_4 = 0;$$

hence the Cartesian coordinates of these points are subject to the relations[1]

$$\frac{x^2}{b^2-c^2} = \frac{y^2}{c^2-a^2} = \frac{z^2}{a^2-b^2},$$

that is, to

$$x^2 + y^2 + z^2 = 0, \quad \text{and} \quad a^2x^2 + b^2y^2 + c^2z^2 = 0.$$

It may, however, be remarked that a double point is not always a

---

[1] See Salmon's *Surfaces*, last paragraph on page 423.

conical point; the cone would be two planes for some double points. Since

$$\varpi^2 + \lambda_1 \lambda_2 \lambda_3 \lambda_4 = 0,$$

then
$$\lambda_1 = 0, \quad \lambda_2 = 0, \quad \lambda_3 = 0, \quad \lambda_4 = 0$$

are the tangential equations of the four real conical points, and therefore, from what we have already said, the Cartesian coordinates of these points are written down from, say

$$\lambda c \sqrt{a^2 - b^2} + \nu a \sqrt{b^2 - c^2} - \sqrt{a^2 - c^2};$$

that is,
$$X = \pm c \sqrt{\frac{a^2 - b^2}{a^2 - c^2}},$$

$$Y = 0,$$

$$Z = \pm a \sqrt{\frac{b^2 - c^2}{a^2 - c^2}},$$

as is well known.

The equation of the tangent cone at a conical point may be calculated in various ways, and referred to its vertex as origin, has for its equation

$$\frac{x^2}{b^2 - c^2} - \frac{(a^2 - c^2) y^2}{4 a^2 c^2} + \frac{z^2}{a^2 - b^2} + \frac{(a^2 + c^2) xz}{ac \sqrt{(a^2 - b^2)(b^2 - c^2)}} = 0,$$

the axes are parallel to the axes of the ellipsoid of elasticity.[1]

Now, since this cone has for its vertex $x_1 y_1 z_1$ and envelopes the ellipsoid,

$$\Sigma \equiv \frac{x^2}{c^2 (a^2 + b^2)} + \frac{y^2}{2 a^2 c^2} + \frac{z^2}{a^2 (b^2 + c^2)} - \frac{1}{c^2 + a^2} = 0,$$

its equation is[2]
$$\Sigma \Sigma_1 - P^2 = 0,$$

and the reader can verify that the equation is equivalent to the form just given when the values of $x_1 y_1 z_1$ are substituted.[3]

---

[1] See Dublin Moderatorship Examination, 1845; Griffin's *Tract on Double Refraction;* or Bassett's *Physical Optics*, page 123.

[2] $P = 0$ is the polar plane of $x_1 y_1 z_1$ with respect to $\Sigma = 0$.

[3] In connexion with what has been written, the reader might consult the footnote on page 438, Art. 405, of Salmon's *Surfaces;* and for an interesting proof that the plane $l_1 = 0$ touches the wave surface in a circle, see page 184 of the *Solutions of the Cambridge Problems and Riders* for 1878, edited by Dr. Glaisher; he ought also to look up the footnote on page 273, Art. 192, of Preston's *Theory of Light* (first edition).

The four polar planes of the conical points with respect to $\Sigma = 0$ consist of two pairs of parallel planes, and any two not parallel are equally inclined to the circular sections of the ellipsoid of elasticity. I have calculated the volume of a singular tangent cone cut off by the polar plane of its vertex with reference to $\Sigma = 0$; its value appears to be

$$\frac{\pi}{6} \cdot \frac{a^2 c^2 \left(a^2 - b^2\right)^2 \left(b^2 - c^2\right)^2}{b^3 \left(a^2 + c^2\right)^3},$$

which I leave to the reader to verify.

XLIX.

ON THE ROTATION-PERIOD OF THE "GARNET" SPOT
ON JUPITER. By ARTHUR A. RAMBAUT, M.A., D.Sc.,
F.R.A.S.

OBSERVATIONS of Jupiter's telescopic appearance have been especially interesting during the present opposition of the planet, on account of the conspicuous markings which have been developed on its surface since it was lost to sight in the Sun's rays.

When Jupiter reappeared last autumn from conjunction, it was found that two new, well-defined, dark spots had broken out in what is known as the north tropical zone. These seem to have been first observed by M. Antoniadi of the Observatory of Juvisy, who, writing to the *Bulletin de la Société Astronomique de France*, describes the second—the following—of these as " rouge grenat très foncé," and says that on October 15th it was so dark that it might have been taken at first for the shadow of a satellite.

In respect of shade, this spot is quite remarkable, standing out more distinctly than any of the other markings on the disc, and has, as a matter of fact, been mistaken by more than one observer (who on looking at the planet was unaware of its existence) for the shadow of a moon, until a reference to the Ephemeris showed that none of the moons were in a position to cast such a shadow at the time.

This spot covers about 5°·5 in zenographical longitude, and about half that in latitude, and is of a very well-defined oval form. Its actual linear dimensions are about 4200 miles long by about 2000 miles broad.

Apart from any theory as to the nature and mode of genesis of these spots, whether they be due to upheavals of the matter forming the visible surface of Jupiter in a manner somewhat analogous to the origin of sunspots, or to the formation of dark clouds in his atmosphere, or to the temporary withdrawal of a heavy pall of vapours, thus forming a rift through which we get a glimpse of the interior parts of the planet, it will be obvious that observations of the movements of such spots must be of great value, as enabling us to determine the elements of the rotation of the planet—the position of its polar axis, and the time in which it completes a rotation.

Since the time of Schroeter the movements of many such spots have been observed, and the curious result is arrived at, that different parts of the surface rotate at different rates.

It will of course be understood that this anomalous behaviour is quite independent of the fact, that the equatorial parts move with a higher linear velocity than those nearer the poles, a law which must hold for any rotating solid sphere such as the Earth or Mars. But in the case of Jupiter it is found that the different spots complete a rotation in different periods, a state of affairs which is quite incompatible with their being each rigidly attached to a solid rotating body.

In this respect Jupiter resembles the Sun itself, where the rate of movement of spots on the whole diminishes as the spot is more and more removed from the equator.

In the case of Jupiter this variation is scarcely so regular as in that of the Sun, but there are distinct differences in the periods of rotation of different zones which conspire with other facts in regard to its physical character, such as its low density (less than one quarter that of the Earth and only 1·29 compared with that of water), and the marked polar compression of its globe, in leading us to the conclusion, that we are here dealing with a body, to a great extent at least, in a state of vapour.

As was pointed out recently by Mr. A. Stanley Williams in the *Monthly Notices of the Royal Astronomical Society*, there are nine distinctly marked zones, whose periods of rotation have been well determined.

These are :—

Zenographical Zones.

Zone.	Latitude.				Period.
I.	+ 85°	to	+ 28°		9^h 55^m 37·5^s.
II.	+ 28	,,	+ 24		9 54½ — to 9^h 56½^m.
III.	+ 24	,,	+ 20		9 48 — to 9 49½.
IV.	+ 20	,,	+ 10		9 55 33·9.
V.	+ 10	,,	− 12		9 50 20.
VI.	− 12	,,	− 18		9 55 40.
VII.	− 14	,,	− 28		9 55 40. (The *Red* Spot.)
VIII.	− 18	,,	− 37		9 55 18·1.
IX.	− 37	,,	− 55		9 55 5.

The "Garnet" spot to which our observations relate is situated in Zenographical latitude + 13°, and is therefore included in Zone IV. of Mr. Williams' paper.

The observations were made with the "South" equatorial refractor, and the Pistor and Martin's filar micrometer, which contains two movable parallel wires at right angles to a single fixed one. The micrometer was set, so that the movable threads were parallel to the direction of the system of belts, and the single wire set, so as to bisect the equatorial diameter of the planet, as
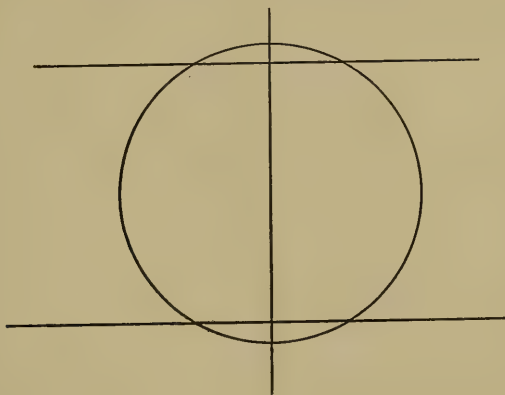
Fig. 1.

represented in figure 1. The wires being kept in this position, the time was noted, at which the preceding end of the spot first touched the wire, that at which the spot was bisected by the

wire, and the moment of last contact with the wire: the mean of all three being taken as the time of apparent central transit of the spot.

This time of apparent central transit is affected by three distinct sources of error, which cannot be ignored when accurate results are sought. These may be described as (1) *the correction for parallax*, (2) *the correction for the velocity of light, and* (3) *the correction for phase*.

Taking these in order we have :—

(1). The correction for parallax. This is due to the change in the relative positions of Jupiter and the Earth in the interval between two apparent central transits. By the period of rotation is of course meant a " sidereal " rotation, *i.e.* the interval which elapses between two transits of the spot, as it would appear
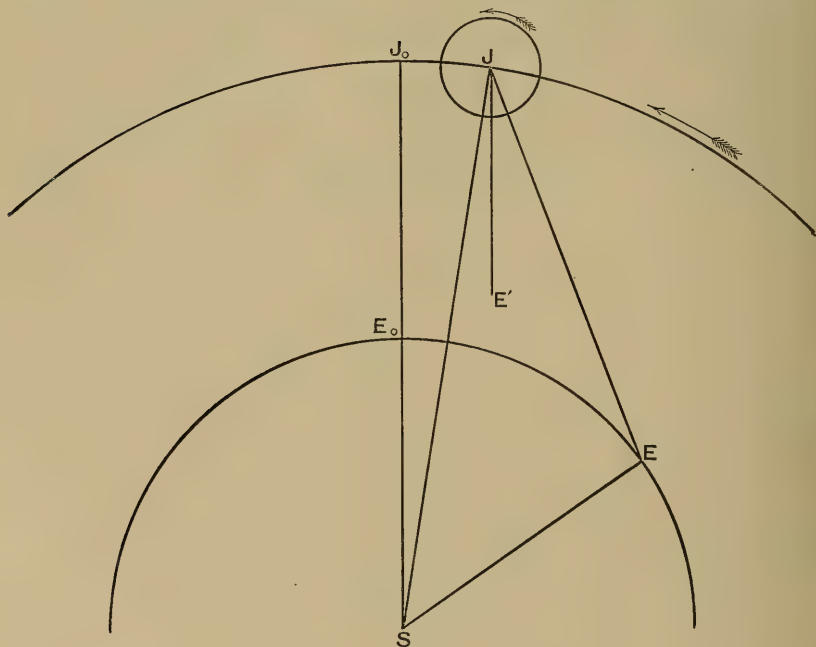
Fig. 2.

from a fixed point at an infinite distance. This is very different from the interval between two transits, as seen from a moving body like the Earth, comparatively speaking, in the vicinity of the planet.

We must, therefore, in the first instance reduce the time of transit to what it would have been if seen from some particular direction. For this purpose it is convenient to select the longitude of the Sun at opposition, represented in fig. 2 by the line J_0E_0S, or the line JE' which is parallel to it. We thus see that previous to opposition the spot will transit with regard to this line before the apparent transit takes place, and after opposition the apparent will take place before the real central transit. That is to say, that before opposition we must diminish the time of observation by the interval which the spot takes to move through the angle $E'JE$ in the figure, whereas after opposition the correction will be a positive one.

To calculate its amount, we remark that the angle

$$E'JE = SJE - J_0SJ.$$

But if L and L_0 denote the longitude of Jupiter at J and J_0, and if l represent the longitude of the earth at E, and if R and D denote the distances of the Sun and Jupiter expressed in units of the mean distance of the Earth from the Sun (all of which may be obtained from the *Nautical Almanac*), we see that

$$\sin SJE = \sin JSE \cdot \frac{R}{D},$$

or

$$SJE = \sin^{-1}\left(\frac{R}{D}\sin JSE\right) = a, \text{ say.}$$

Also,

$$J_0SJ = L_0 - L, \quad \text{and} \quad JSE = L - l,$$

so that the correction which is to be *added* is the time of describing the angle

$$SPE = \sin^{-1}\left\{\frac{R}{D}\sin(l-L)\right\} + \left(L_0 - L\right).$$

Knowing *approximately* the time of rotation (P), we have, finally, the correction for parallax

$$= \left[\sin^{-1}\left\{\frac{R}{D}\sin\left(l - L\right)\right\} + \left(L_0 - L\right)\right] \times \frac{P}{2\pi} \quad . \quad . \quad . \quad \text{(A.)}$$

(2). *The correction for the velocity of light.*—In consequence of the finite velocity of light, any phenomenon taking place on Jupiter will not be seen by us, even at opposition, for thirty-five

minutes after its occurrence. Of course, if this delay or retardation were constant, it would not affect our observations, but on account of our constantly changing distance from the planet this retardation will vary between wide limits. Comparing again our observations with those made at the moment of opposition, we see that the correction to be applied is the difference in the times which light requires to travel the distances JE and J_0E_0 (fig. 2). If T is the time which light occupies in traversing the mean radius of the Earth's orbit (viz. $8^m \cdot 317$), this correction is therefore evidently—

$$\left(D_0 - D\right) T = -\left(\frac{D}{D_0} - 1\right) \times D_0 T \quad . \quad . \quad . \text{ (B.)}$$

We have, lastly,

(3). *The correction for phase.*—Although the great distance of Jupiter from the Earth prevents its ever assuming a very marked gibbosity, as is seen at each synodical revolution in the case of Mars, yet there is a certain amount of phase which will sensibly affect observations, such as those with which we are at present concerned. For, the phase is so small—the defect of the diameter
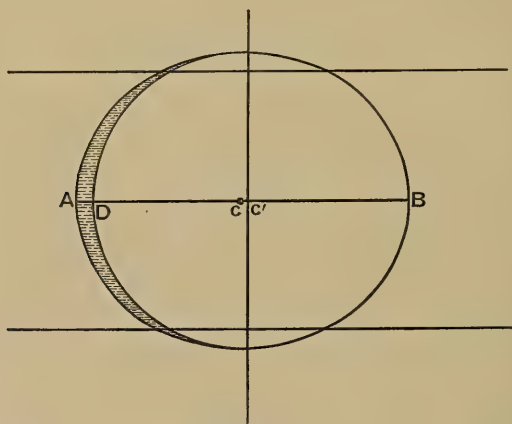
Fig. 3.

never exceeding $0'' \cdot 35$—that to the eye the form of the disc is always perfectly symmetrical, and consequently the method above described of setting the micrometer will have the effect of placing the single wire so as to pass through C', the middle point of BD (in fig. 3), instead of through C, the middle point of AB,

and it is clear that the amount of displacement CC' is half the defect AD.

To calculate the amount of this correction, we remark that in fig. 4 (in which the circle $AD'B$ represents the equator of Jupiter, and JS and JE the *directions* in which the Sun and Earth respectively lie—*cf.* fig. 2), the arc BD' measures the proportion of the illuminated hemisphere visible at the time, and since the

Fig. 4.

apparent disc is an orthogonal projection of the visible portion of the illuminated hemisphere of the planet, we see that JC'' is the amount of the displacement of the centre due to phase, and this is equal to $\frac{1}{2}AD$. But $AD = \frac{1}{2}AB\,(1 - \cos\,AJD') = \frac{1}{2}AB \times (1 - \cos\,SJE)$. Also, the angle CJC' being very small, we may take its arc CC' as equal to its chord, *i.e.* $CC' = JC'' = \frac{1}{4}\,AB \times (1 - \cos\,SJE)$. Now the time of moving from C' to C is the same fraction of the whole period that the arc CC' is of the whole circumference of the equator, or

the correction for phase $= \frac{1}{4}AB\,(1 - \cos\,SJE) \times \dfrac{P}{\pi AB}.$

Also, SJE is the angle we have already denoted by a, so that we have, finally,

the correction for phase $= \sin^2 \frac{1}{2}a \times \dfrac{P}{2\pi},$ . . . (C.)

It is obvious, too, that before opposition this correction will be positive, and after opposition, negative.

I now come to the actual observations, which were made at
Dunsink, on every available opportunity, between February 9th
(when my attention was first directed to the spot) and March 16th.
The first four observations were made by my assistant, Mr. Charles
Martin ; the others by myself.

In the following table (p. 397) I give the actually observed times
of transit expressed in Greenwich mean time, the three corrections
referred to above, and the corrected times of central transit.   In
the last column is given the number of revolutions which had
taken place since the first observation.

We have next to consider the treatment of the observations
for the deduction of the period of rotation. We must assume
that each of these observations, the first included, is affected with
a certain amount of error.   If then we assume that the first
transit took place at some epoch (T_0) nearly, but not exactly,
coincident with the time of the first observation (T_1), and if we
denote the number of revolutions which have elapsed between
T_0, and any subsequent transit by r, each observation will give
us an equation of the form—

$$T_0 + rP = T_n.$$

Now, if we take $T_0 = T_1 + x$, where x is a small correction to
be determined, and $P = P_0 + y$ where $P_0 = 9^h 55^m 34^s$, and y is a
small correction, we have

$$T_1 + x + r(P_0 + y) = T_n,$$
or $$x + ry = T_n - T_1 - rP_0 = n.$$

In this way we find the following equations of condition,
taking $T_0 =$ Feb. 9th, $8^h 12^m 56^s$ (G. M. T.) :—

No.	Equations of Condition.	Residuals.	Weight.	Observer.
1.	$x + \ 0. \ y = \quad 0$	$- 1^m 24^s$	1	C.M.
2.	$x + \ 3. \ y = - 311$	$+ 3 \quad 45$	1	,,
3.	$x + \ 5. \ y = + 186$	$- 4 \quad 33$	$\frac{1}{4}$	,,
4.	$x + 10. \ y = - \ 92$	$+ \quad 1$	1	,,
5.	$x + 27. \ y = - 103$	$+ \quad 1$	1	A.A.R.
6.	$x + 29. \ y = - 136$	$+ \quad 33$	1	,,
7.	$x + 34. \ y = - \ 28$	$- 1 \quad 18$	1	,,
8.	$x + 41. \ y = - \ 35$	$- 1 \quad 15$	1	,,
9.	$x + 51. \ y = - 107$	$- \quad 10$	1	,,
10.	$x + 70. \ y = - 118$	$- \quad 11$	1	,,
11.	$x + 87. \ y = - 204$	$+ 1 \quad 4$	1	,,

TIMES OF CENTRAL TRANSIT OF THE "GARNET" SPOT ON JUPITER.

Date.	Time.	A.	B.	C.	Corrected Time.	No. of Revs.
February 9th,	8ʰ 9ᵐ 54ˢ·7	+ 209ˢ·2	− 22ˢ·6	− 5ˢ·0	9ᵈ 8ʰ 12ᵐ 56ˢ	0
„ 10th,	13 51 14·7	+ 223·9	− 26·1	− 5·8	10 13 54 27	3
„ 11th,	9 50 33·6	+ 233·6	− 28·4	− 6·3	11 9 53 52	5
„ 13th,	11 23 28·9	+ 257·2	− 34·8	− 7·7	13 11 27 4	10
„ 20th,	12 7 14·4	+ 331·3	− 61·0	− 13·3	20 12 11 31	27
„ 21st,	7 57 45·6	+ 339·3	− 64·5	− 14·0	21 8 2 6	29
„ 23rd,	9 37 15·0	+ 358·2	− 73·7	− 15·8	23 9 41 44	34
„ 26th,	7 5 57·4	+ 383·8	− 87·6	− 18·5	26 7 10 35	41
March 1st,	10 20 18·0	+ 415·8	− 108·8	− 22·3	30 10 25 3	51
„ 9th,	6 55 58·8	+ 462·8	− 154·4	− 29·6	38 7 0 38	70
„ 16th,	7 39 36·5	+ 489·0	− 200·1	− 35·9	45 7 43 50	87

These lead to the normal equations—

$$10 \cdot 25\,x + \quad 353 \cdot 25\,y = - \quad 1087 \cdot 5,$$
$$353 \cdot 25\,x + 19592 \cdot 25\,y = - 42197 \cdot 5,$$

from which we obtain the following solution :—

		Weight.
$x = -$	$1^{\mathrm{m}} 24^{\mathrm{s}} \cdot 2 \quad \pm 36^{\mathrm{s}} \cdot 4$	$3 \cdot 9$
$y = -$	$0 \cdot 64 \pm \quad 0 \cdot 53$	$7420 \cdot 0$;

while the probable error of a single observation is $\pm 72^{\mathrm{s}}$.

We thus get for the period of rotation of the spot—

$$9^{\mathrm{h}} \, 55^{\mathrm{m}} \, 33^{\mathrm{s}} \cdot 36 \pm 0^{\mathrm{s}} \cdot 53,$$

and the epoch from which to reckon the rotations—

$$\text{February 9th,} \quad 8^{\mathrm{h}} \, 11^{\mathrm{m}} \, 31^{\mathrm{s}} \cdot 8.$$

It will thus be seen that this spot is moving at about the average velocity of the zone in which it lies; and it is interesting to note that this period agrees within one-fifth of a second with the value deduced by Schroeter 109 years ago from 242 revolutions of a spot, a fact which goes to show that there has been no permanent change in the period of rotation of this region in the interval which has elapsed since then.

L.

NOTE ON IRISH ANNELIDS IN THE MUSEUM OF SCIENCE AND ART, DUBLIN.—No. I. By W. C. M'INTOSH, Professor of Natural History in St. Andrew's University.

PROFESSOR HADDON lately forwarded a collection of Irish Annelids made during various dredging expeditions. The specimens were preserved with considerable care, and duly labelled. At the same time an extensive series of Annelids from the Science and Art Museum was sent, at the instigation of Dr. Scharff, by the lamented Dr. Valentine Ball. I am much indebted to these gentlemen for their courtesy in handing these over for examination, in order that the forthcoming monograph of the British Annelids might be as complete as possible in regard to distribution.

For convenience, each collection may be placed separately under each species, and in this instance the list goes as far as the Sigalionidæ. It was hoped that, in these collections, examples of the rare *Spinther oniscoides* of Dr. George Johnston would have been present, for his example was dredged by Mr. W. Thompson, in Belfast Bay, in 6–10 fathoms, but no trace of such was found.

The occurrence of two new species, and a few varieties, show that still more is to be done in our country in this group of Invertebrates.

LIST OF IRISH ANNELIDS.

Aphrodita aculeata, L.

Bantry Bay, No. 92, 1892, of moderate size; off Howth (Lambay excursion, 1886), the specimen (3 inches) having *Loxosoma* and a Campanularian parasitic on the feet and the ventral surface; Station 114, 80 fathoms, young example; Station 122, young; Station 126, small; Stations 127 and 128, two of moderate size; Station 147, small.

[*In Science and Art Museum.*]

Berehaven, $1\frac{1}{2}$ inches; off Howth (Lambay excursion, 1886); S.-W. Ireland, log. 55, 23–35 fathoms; R. I. A. Exped., 1886, small; log. 53, 70–80 fathoms, R. I. A. Exped., 1886, R. Scharff, small; off Baltimore, S.-W. Ireland, 34 fathoms, 1855; Bantry Bay (82), 1892.

Lepidonotus squamatus, L.

Blacksod Bay (6), July, 1890; Salthill, Co. Dublin; S.-W. Ireland, A. G. More; Dalkey, Co. Dublin, A. C. Haddon, 1855; mouth of Bantry Bay, 37–35 fathoms, 1885; R. I. A. Exped., Station xxx, No. 171, June, 1890.

[*In Science and Art Museum.*]

Berehaven, 1886, one bearing ova; Glandore, S.-W. Ireland, 4 fathoms; R. I. A. Exped., 1883, young; Malahide, 1886, A. C. Haddon; North of Ireland Ord. Surv. Coll., Bantry Bay, 1892.

Lepidonotus clava, Mont.

Variety, with the tips of the ventral bristles longer; Bantry Bay (107 and 103), 1892.

Nychia cirrosa, Pall.

Prof. Haddon, mouth of Bantry Bay, 37–35 fathoms, 1885, small; ibid., 1892; Blacksod Bay (5), June, 1890, along with tube of *Lanice conchilega.*

[*In Science and Art Museum.*]

Berehaven, S.-W. Ireland Exped., 1886; Broadhaven Bay, A. G. More, very large; Dalkey Sound, 1892, medium.

Lagisca propinqua, Malmgren.

S.-W. Ireland Exped. (53), 1886.

[*In Science and Art Museum*].

Glandore, S.-W. Ireland Exped. (35), 4 fathoms; R.I.A. Exped., 1886; Berehaven, R.I.A. Exped., 1885; Bantry Bay (33), 39–35 fathoms, 1885; and (103 and 177), 1892; Malahide, 1886, A. C. Haddon; Great Arran Island, Co. Galway; Berehaven, R. I. A. Exped., 1886; Nymph Bank, S. Ireland.

Harmothoë imbricata, L.

[*In Science and Art Museum.*]

Station xxx (171), June, 1890, variety; Baltimore Bay, December, 1889, Father Davies; Bantry Bay (42), $3\frac{1}{2}$ fathoms; R. I. A. Exped., 1886; Bundoran, Donegal, August, 1889, Dr. Scharff; specimen, locality not marked; Salthill, Co. Dublin, A. C. Haddon; Blacksod Bay (5), July, 1890; Long Island Sound (40), $3\frac{1}{2}$-5 fathoms; R. I. A. Exped., 1886; Berehaven, R. I. A. Exped., 1885; Bantry Bay (177), 1892; Malahide, Co. Dublin, A. C. Haddon; Broadhaven Bay, A. G. More; Dingle Bay (152), 1889; Portmarnock, October, 1889, R. Scharff.

Harmothoë Fraser-Thomsoni, n. sp.[1]

S.-W. Ireland Exped. (46); 93 fathoms, R. I. A. Exped., 1886, along with *Malmgrenia castanea* on *Spatangus Raschi*. This species, which had been procured by the "Knight Errant," in the Atlantic in 1880, is characterized as follows:—

Head somewhat near that of *Lagisca*, having a pair of widely separated eyes posteriorly, and a larger pair on the lateral eminence. Palpi of moderate length, with rows of minute papillæ. Body of considerable length and breadth; bristled segments 39–40. Dorsum has touches of brown pigment, posteriorly, as in *Lagisca*. The lateral nephridial eminences are prominent, but there are no papillæ. Scales, 15 pairs, mottled-brown, covering the dorsum; first, small and rounded; rest, more or less ovoid; border smooth, anterior and inner half studded with small horny papillæ, outer and posterior areas have sparsely distributed large tubercles, with an interrupted row along the posterior border. Dorsal bristles stout, moderately long, and slightly curved, with closely arranged spinous rows, and a short smooth tip. Ventral bristles bifid, the secondary process coming off at an angle. Dorsal cirri appear as if fusiform from the gradual nature of the dilatation and the long filiform tip, and have clavate cilia. Ventral cirri slender, with a few clavate cilia.

---

[1] Figures will be found in the forthcoming Part II. of the British Annelids, Ray Society.

Harmothoë lunulata, D. Chiaje.

[In Science and Art Museum.]

S.-W. Ireland Exped. (44), 108 fathoms; R. I. A. Exped., 1886.

Evarne impar, Johnston.

[In Professor Haddon's Collection.]

Long Island Sound (40), 3½–5 fathoms; R. I. A. Exped., 1886; Salthill, Co. Dublin, A. C. Haddon; Blacksod Bay (6), July, 1890.

[In Science and Art Museum.]

Berehaven, R. I. A. Exped., 1885; S.-W. Ireland Exped. (31), 39½ fathoms; R. I. A. Exped., 1886; Glandore (35), 4 fathoms; R. I. A. Exped., 1886, with remarkably mottled scales; Bantry Bay (103), 1892.

Evarne Johnstoni, M'Intosh.

[In Royal Dublin Society's Collection.]

Station 115, 62–52 fathoms, Aug. 20th, 1890.

Antinoë finmarchica, Malmgren.

This rare form was dredged at No. 56, in 93 fathoms, during the R. I. A. Exped., 1896. It is an inhabitant of deep water, and had previously been got on the West Coast of Ireland, and during the "Porcupine" Expedition of 1869, at considerable depths.

Malmgrenia castanea, M'Intosh.

[In Professor Haddon's Collection.]

S.-W. Ireland Exped. (No. 46), 93 fathoms, on *Spatangus Raschi* (23, 56), 15th July; R. I. A. Exped., 1886.

[In Science and Art Museum.]

S.-W. Ireland Exped. (48), 480 fathoms; R. I. A. Exped., 1886.

Alentia gelatinosa, Sars.

[In Royal Dublin Society's Collection.]

Killeany Bay (*in litt.*), 3rd June, 1890, large; Blacksod Bay, trawl, 5th July, 1890, ♀ carrying ova; Birturbuy Bay, 10th June, 1890.

[*In Science and Art Museum.*]

Berehaven, R. I. A. Exped., 1885, small.

Polynoë scolopendrina, Sav.

[*In Royal Dublin Society's Collection.*]

Blacksod Bay, 6th July, 1890; Bantry Bay (23), 37–35 fathoms, R. I. A. Exped., 1885; Dalkey, Co. Dublin, A. C. Haddon; in tube of *Terebella*?

[*In Science and Art Museum.*]

Berehaven, R. I. A. Exped., 1886, good specimens; Ibid., 1885; Dingle Harbour, A. G. More.

Sthenelais boa, Johnston (= *S. Idunæ*, H. Rathke).

[*In Professor Haddon's Collection.*]

Off Bray Head, Co. Wicklow, A. C. Haddon, 23 fathoms (116), 1892.

[*In Science and Art Museum.*]

Malahide, Co. Dublin, A. C. Haddon, 1886; small (young). Berehaven, R. I. A. Exped., 1885, good; Broadhaven Bay, A. G. More.

Sthenelais limicola, Ehlers.

[*In Royal Dublin Society's Collection.*]

Mouth of Kenmare River (21), 41 fathoms, R. I. A. Exped., 1885.

[*In Science and Art Museum.*]

S.-W. Ireland Exped. (48), 480 fathoms; R. I. A. Exped., 1886; Ibid. (55), 23–38 fathoms; R. I. A. Exped., 1886, mouth of Kenmare River, *ut supra*; S.-W. Ireland, Station v., 1885; R. I. A. Exped.

Sthenelais,[1] n. sp.

Dredged off the South-west of Ireland, log. 45, at 328 fathoms: R. I. A. Exped., 1886.

Head absent; body seemed to be long and narrow, with prominent feet; only the posterior region remained. Scales, on every foot on the posterior fragment, large, covering the entire

---

[1] It is unsafe to name imperfect specimens, but this form should bear the title, *S. Haddoni*.

dorsum of the narrow body, and uniform in outline. They are perfectly smooth on surface and border, and thus differ from those of the other British species. A shallow notch occurs at the external margin, and a more acute one at the hilum. The distribution of the nerves is well seen.

The feet have an unusually long, straight branchial process dorsally, and three ciliated pads beneath it on the dorsal curve. The dorsal lobe is clavate (narrower at the base), much bevelled dorsally at the tip, and with a long, slender papilla stretching from the apex. The dorsal bristles form a long tuft of rather boldly serrated bristles superiorly, and they diminish towards the ventral edge; the ventral lobe forms an irregular spear-head, the longer slope being inferior, and the apex from which the spine projects is prominent, and bears a papilla. Inferiorly is another prominence behind the lower group of bristles. The upper ventral bristles are slender, the distal ends of the shafts having eight or nine whorls of spikes, the terminal process apparently being simple—in the form of a tapering acicular process with a needle-like tip, a condition probably due to repair, since some show a many-jointed needle-like tip. Others, with stronger shafts, next follow, with shorter, simple tips numerously jointed. Some of the more slender shafts at the ventral border of the stout series present many-jointed tips, with a minute claw. Then follows a large, fan-shaped group of most slender bristles, with a few spines at the tips of the slightly-curved shafts, and long (6–8) jointed, hair-like tips. The ventral cirrus is long and subulate, and its tapering tip reaches as far as the apex of the ventral lobe.

So far as can be observed, this is the nearest approach to *Leanira*, only the more slender forms of the stouter series of bristles in the ventral division presenting a very finely bifid extremity.

Pholoë minuta, Fabricius.

[*In Royal Dublin Society's Collection.*]

Kilronan Bay, Aran Isles, 3rd June, 1890.

LI.

THE HYDROIDS OF THE IRISH COAST. By J. E. DUERDEN, A.R.C. Sc. (Lond.); Curator of the Museum, Kingston, Jamaica.

HAVING left Ireland, I have considered it advisable to summarize my results, however incomplete, of the known species of Irish Hydroids, upon numerous collections of which I have been employed for two or three years. The list also contains the records of those whose occurrence has been noted by other workers in the group. The following are the principal publications referring to Irish forms :—

Dr. A. Hill Hassall, in a "Catalogue of Irish Zoophytes," and in a "Supplement" to the Catalogue, made the first attempt at a list of the Irish Hydroids (1841*a*, 1841*b*).

Mr. William Thompson, in his "Natural History of Ireland," gives a number of localities for different species (1856).

Prof. G. J. Allman has described and referred to, in various publications, a number of representatives obtained from Ireland.

In the "British Hydroid Zoophytes" (1868) the Rev.T. Hincks summarizes, under each species, the Irish localities where rarer forms are known to occur, being indebted mainly to the lists and collections of Prof. Allman, Dr. Hassall, Mr. W. Thompson, Prof. Wyville Thomson, and Mr. G. S. Brady.

"The British Association Guide to the County of Dublin" (1878) records about fifty species for this part of the coast, from the collections of Mr. M'Calla, Dr. Hassall, Prof. J. R. Greene, Hon. Miss Lawless, Mr. D. St. J. Grant, and Prof. H. W. Mackintosh.

Prof. Haddon, in a "Preliminary Report on the Fauna of Dublin Bay" (1886), adds several species.

Mr. Kirkpatrick (1889) records the specimens obtained on a deep-sea trawling expedition off the south-west of Ireland.

Prof. Herdman, during the cruise of S. Y. "Argo" round the west coast of Ireland (1889), obtained fourteen species of Hydroids. My own results are founded upon the material collected by the different Fishery Surveys of the West Coast, undertaken by the Royal Irish Academy (1893) and the Royal Dublin Society (1895); also upon collections made on expeditions in connection with the " Royal Irish Academy Fauna and Flora Committee " to the Bantry Bay district and to Donegal Bay, and upon various collecting trips on the east coast (1894 *a*, 1894 *b*). Some of these results have already been embodied elsewhere. In all, my examinations make an addition of about twenty-three to the Irish Hydroids, including two new species and one new to Britain.

The present list contains 101 species—35 Athecata and 66 Thecata. The west coast is much richer in the former group than is the east coast, yielding many of the minuter species.[1]

Order.—HYDROIDA.

Sub-Order.—I. Athecata.

I. CLAVIDÆ.

Clava multicornis, Forskål.

Obtained growing profusely on the limbs and carapace of *Inachus*, from Lough Swilly; on *Stenorhynchus*, from Killybegs; Ballinskelligs Bay, at a depth of 55 fathoms (R. D. S.); Dursey Sound; Kenmare River; Berehaven; abundant on *Fucus*, from Roundstone; Donegal Bay rock-pools (J. E. D.).

Clava squamata, Müller.

Recorded in the British Association List for county Dublin (1878).

Tubiclava lucerna, Allman.

Obtained by Prof. Allman on stones between tide-marks in Dublin Bay (1863). It does not appear to have since been found on the Irish coasts.

---

[1] Since this Paper was written, Mr. F. W. Gamble has published (*Irish Naturalist*, May, 1896) " Notes on a Zoological Expedition to Valentia, Co. Kerry," in which he records several Hydroids obtained.

Tubiclava cornucopiæ, Norman.

A rare species collected by the Royal Dublin Society's Survey from Blacksod Bay. Colonies were found living on four different shells of *Astarte sulcata*, with the living animal inside (1895).

II. HYDRACTINIIDÆ.

Hydractinia echinata, Fleming.

A common species, living on shells inhabited by hermit-crabs; obtained in abundance from all localities where dredging has been carried on.

III. PODOCORYNIDÆ.

Podocoryne carnea, Sars.

First recorded for Ireland from collections made by the Royal Irish Academy from Long Island Bay (1893); Galway Bay, on *Nassa*; Blacksod Bay, on *Aporrhais* (R. D. S.).

Podocoryne areolata, Alder.

Obtained among the collections from the deep-sea trawling expedition off the south-west coast of Ireland (1889); Dursey Head and Berehaven (1893).

IV. CORYNIDÆ.

Coryne pusilla, Gærtner.

A fairly common form in the rock-pools. On *Fucus*, Berehaven (R. I. A.); on *Zanthea*, Kilkeiran Bay (R. D. S.); rock-pools of Donegal Bay; Dursey Island; Rush (J. E. D.).

Coryne vaginata, Hincks.

Tide-pools of Clew Bay (Hincks); common on the southern shores and in Dublin Bay (Allman); north-east coast (W. Thompson).

Coryne van Benedenii, Hincks.

Placed in the county Dublin list as rare at Killiney Bay (Hon. Miss Lawless).

Syncoryne frutescens, Allman.

Found at Kingstown, county Dublin, attached to floating logs in a reservoir exposed to the tide, and constantly supplied by sea-water from Dublin Bay (1872).

Syncoryne eximia, Allman.

On sea-weed from Scotch Bay, Kingstown (1886). Owing to the absence of gonophores, Professor Haddon considers this identification not absolutely certain.

V. CLAVATELLIDÆ.

Clavatella prolifera, Hincks.

Coasts of Cork (1872).

VI. EUDENDRIIDÆ.

Eudendrium rameum, Pallas.

A colony of this species, perfect as a miniature tree with the gonophores as fruit, was dredged from St. 125, 40 miles off Bolus Head, at a depth of 115 fathoms (R.D.S.). A large *Hyas araneus* from Lough Swilly, collected by the same Survey, had covered itself almost entirely with branches of the Hydroid. Also obtained from many other parts of the coast.

Eudendrium ramosum, Linn.

Collected by the different Surveys from various points of the coast. It is especially abundant on the east coast, being washed ashore in company with various other zoophytes torn up by the trawl.

Eudendrium capillare, Alder.

This more delicate form was obtained growing abundantly on the inside of an old *Pecten* shell from Casheen Bay. The gonophores were (April) undeveloped on any of the individuals. On a sponge from Kilkeiran Bay, rather common, with gonophores on the lower part of the stem ; amongst the shore collections from Blacksod Bay, from off Malin Head, growing on *Fusus* (R. D. S.) ; Berehaven (1893) ; Dublin Bay (1886).

Eudendrium insigne, Hincks.

Lough Swilly (1895).

VI. ATRACTYLIDÆ.

Atractylis arenosa, Alder.

On the west coast at a depth of 50 fathoms (1893); shore collections at Rush, county Dublin (1894b).

Perigonimus repens, T. S. Wright.

Berehaven, growing on *Sertularia abietina*; on *Scaphander*, Galway Bay; off the Skelligs, depth 40 to 80 fathoms; Dingle Bay (1893).

Perigonimus gelatinosus, Duerden.

On shells inhabited by *Pagurus* from rather deep water, Dingle Bay, depth 40 fathoms (R. D. S.); south-west of Ireland, depth 50 fathoms; $9\frac{1}{4}$ miles south-west of Castletown, depth $37\frac{1}{2}$ fathoms (1895).

Perigonimus (?) inflatus, Duerden.

On *Sertularia abietina* and other zoophytes from fairly deep water, 11 miles south of Glandore Harbour, depth 54 fathoms; 13 miles south-west of Galley Head, depth 43 fathoms (1895).

Perigonimus (?) linearis, Alder.

South of Glandore Harbour, depth 54 fathoms (1893).

Garveia nutans, T. S. Wright.

South-west corner of Dalkey Island, associated with *Tubularia humilis* and *T. indivisa* (1886).

Bimeria vestita, T. S. Wright.

Lough Swilly (1895).

Dicoryne conferta, Alder.

This zoophyte, growing on shells inhabited by hermit crabs, is not uncommon on the west coast; found growing luxuriantly, with the gonophores on the branches well developed, around the mouth of a *Buccinum* shell, and also on that of a *Fusus*, from off the Skelligs, depth 50 fathoms; from Kenmare River (R. D. S.); Bantry Bay; Berehaven; at a depth of 50 fathoms off the south-west of Ireland (1893).

Heterocordyle Conybearei, Allman.

This species was founded on specimens growing in considerable abundance on old univalve shells, tenanted by hermit crabs, found at the Harbour of Glengariff, county Cork (1864).

Bougainvillia ramosa, Van Beneden.

Colonies of this hydroid are known from various Irish localities. Several of the specimens bear the club-shaped capsules previously observed on *Hydractinia* and *Syncoryne*, which function as the nests of pycnogon larvæ (Hodge, Ann. Mag. Nat. Hist.). Glandore Harbour, with parasite capsules; Dingle Bay; Berehaven (R. I. A.); off the Skelligs, 80 fathoms; Lough Swilly, from off the shell of a *Buccinum*, and bearing parasite capsules (R. D. S.); Donegal Bay rock-pools (J. E. D.).

Bougainvillia fruticosa, Allman.

Professor Allman founded this species on specimens obtained from a large piece of floating timber in the estuary of the Kenmare River (1864). On limbs of *Stenorhynchus*, with nest of larval *Pycnogonida*, Bantry Bay (1895).

VII. TUBULARIIDÆ.

Tubularia indivisa, Linn.

Generally distributed on our coasts. Dredging in Dalkey Sound yields fine specimens.

Tubularia larynx, Ell. and Sol.

Belfast Lough (W. Thompson); obtained in considerable abundance in the luxuriant rock-pools of Bundoran, and at several other points around the coasts (J. E. D.).

Tubularia simplex, Alder.

From Berehaven, growing on an old *Pecten* shell (1893).

Tubularia bellis, Allman.

Dursey Island, on the sides of the rocks at extreme low-water with the gonophores well developed (J. E. D.).

Tubularia humilis, Allman.

On rocks above the level of low-water spring tides, near the mouth of Kinsale Harbour (1864) ; Dalkey Island (1886).

Ectopleura Dumortierii, Van Beneden.

Of this species Mr. Hincks says :—" Professor Wyville Thomson has recorded the occurrence of this Belgian zoophyte in Belfast Bay ; but specimens of the dried polypary from this locality, which he has kindly sent me, are much stouter and of coarser texture than any examples I have seen of *E. Dumortierii*, and, I believe, must be referred to some other species " (1868).

Corymorpha nutans, Allman.

Professor Haddon, dredging in Scotch Bay, Kingstown, had the good fortune to obtain two specimens of this species (1886).

Sub-order.—II. Thecaphora.

I. CAMPANULARIIDÆ.

Clytia Johnstoni, Alder.

One of our commonest zoophytes. Some much-branched forms, with gonothecæ, were obtained from Queenstown, growing on *Aporrhais* ; and another, with very large calycles and stems branched, was found growing in small tufts on a *Lernæa* parasitic on a whiting (R.D.S.).

Obelia geniculata, Linn.

Plentiful from all parts, growing especially on *Laminaria*.

Obelia gelatinosa, Pallas.

This species does not seem to be common around the Irish coasts, as it has apparently not been before recorded. I have, however, found fine colonies in the rock-pools of Howth.

Obelia longissima, Pallas.

A single colony, about nine inches long, with gonothecæ, was obtained by the Royal Dublin Society Survey from Galway Bay ; Howth (M'Calla) ; Donegal Bay (J. E. D.).

Obelia dichotoma, Linn.

Common from most localities.

Obelia flabellata, Hincks.

Abundant in the rock-pools of Bundoran ; Donegal Bay Roundstone (J. E. D.) ; " Argo " Cruise (1891).

Campanularia volubilis, Linn.

A somewhat common species growing mostly on other zoophytes. Blacksod Bay ; Port Stewart ; off Malin Head (R. D. S.) ; Dursey Island ; Dublin Bay (J. E. D.).

Campanularia Hincksii, Alder.

Common in deep water in the north of Ireland (Wyville Thomson) ; abundant in Dublin Bay (J. E. D.).

Campanularia integra, Macgillivray.

Recorded for Ireland only from Belfast Bay (1868).

Campanularia verticillata, Linn.

Occasionally trawled in Dublin Bay, and also found washed ashore after storms.

Campanularia caliculata, Hincks.

Obtained by Professor Allman from Courtmasherry Harbour, County Cork ; by R. Allman from Old Head of Kinsale, county Cork ; Dublin Bay

Campanularia flexuosa, Hincks.

Collected from most localities. Very abundant in the rock-pools around Bundoran. On specimens from Berehaven many of the gonothecæ contained small Nematodes.

Campanularia angulata, Hincks.

Recorded from several localities growing on *Zostera marina*, its favourite habitat.

Campanularia neglecta, Alder.

Dalkey Sound, growing on other zoophytes (J. E. D.) ; Blacksod Bay (R. D. S.) ; " Argo " Cruise (1891).

Campanularia raridentata, Alder.

Glandore Harbour, growing on *Bougainvillia ramosa* (1893); Ballycotton, on worm-tubes; Blacksod Bay, on *Sertularella polyzonias* (R. D. S.).

Gonothyræa Lovéni, Allman.

Although not recorded in the Dublin List, I have found this interesting species in great abundance, practically covering all the *Fucus* for a considerable area, under the wooden bridge leading to the North Bull, Dublin Bay.   All stages in the development of the sporosacs could be followed.   At this spot I have likewise obtained the variety mentioned by Professor Allman as forming "long, lax tufts, in some cases three or four inches long."   Abundant on *Fucus* from Lough Atalia (R. D. S.); Dublin Bay (1886); Carrickfergus; Monkstown, near Cork (Wyville Thomson).

Gonothyræa gracilis, Sars.

Dredged by Mr. G. S. Brady in Birterbuy Bay, Connemara, growing on the tests of Ascidians and other objects (1864).

Gonothyræa hyalina, Hincks.

On *Hydrallmania falcata*, from Port Stewart, showing the gonothecæa (R. D. S.); on the shore between Laytown and the mouth of the Boyne (1894 *a*).

II. CAMPANULINIDÆ.

Campanulina turrita, Hincks.

On *Zostera*, Holywood, Belfast Lough (Wyville Thomson); Blacksod Bay (R. D. S.); Bantry Bay; Dalkey; Bundoran; Dursey Island; Roundstone, Connemara (1895).

Campanulina panicula, G. O. Sars.

On two *Fusus* shells trawled 40 miles off Achill Head; depth 220 fathoms (1895).

Opercularella lacerata, Johnston.

North of Ireland (Wyville Thomson).

III. LAFŒIDÆ.

Lafœa dumosa, Fleming.

Known from various localities all round the coast.

Lafœa parvula, Hincks.

On *Nitophyllum*, from the north of Ireland, collected by Prof. Hincks, Toronto (1868).

Lafœa pocillum, Hincks.

On *Eudendrium*, at Monkstown (D. St. J. Grant) ; on *Diphasia attenuata*, Dublin Bay (1886) ; on *Vesicularia spinosa*, Killiney (J. E. D.).

Calycella syringa, Linn.

Very abundant, growing on other zoophytes, in dredgings from all parts of the coast.

Calycella fastigiata, Alder.

Apparently a rare British form, but rather plentiful on the west coast of Ireland. On *Sertularia abietina*, Ballinskelligs Bay (R. D. S.) : south-west of Galley Head, 43 fathoms ; Dursey Island, south of Glandore Harbour ; south-west of Ireland, 50 fathoms (1893).

Calycella pygmæa (Alder), Thornley.

This is the *Lafœa pygmæa* of Alder (MS.). It has lately been transferred to the genus *Calycella* (1894) after confirmation of Alder's manuscript figure of it as an operculated form, and the discovery of the gonotheca and gonophore, which, except in size, closely resemble those of *C. syringa*. Previously to seeing Miss Thornley's Paper, I had observed the same character on material gathered at Roundstone, Connemara, and am able to confirm both the presence of the operculum and the extra-capsular gonophore. The hydrotheca in the Irish specimens is not so sharply marked off from the pedicel as in the figures given by Hincks, Pl. xl., and the number of rings may be as many as six or seven, Some specimens also show that, as in *C. syringa*, the upper part may be divided into segments by lines of growth, but I have never seen more than one, while there are occasionally two or three in the latter.

It was found to be rather abundant creeping over *Fucus* collected along the shore at Roundstone. Prof. Haddon obtained the species from Dalkey.

Cuspidella grandis, Hincks.

A rare species, found growing on worm-tubes from Ballycotton, at a depth of 30 fathoms (R. D. S.); Birterbuy Bay, Connemara (G. S. Brady).

Cuspidella costata, Hincks.

On tubes of *Tabularia indivisa*, Berehaven, 1893.

Filellum serpens, Hassall.

Common all around the coast, growing on other zoophytes.

V. COPPINIIDÆ.

Coppinia arcta, Dalyell.

Dredged from most localities, growing principally on *Sertularia abietina.*

VI. HALECIIDÆ.

Halecium halecinum, Linn.
Common.

Halecium muricatum, Ell. and Sol.

Giants' Causeway (Hassall).

Halecium Beanii, Johnston.

Common from all parts.

Halecium tenellum, Hincks.

A small colony, growing on *Tubularia* from the Fairy Bridge, Donegal Bay (J. E. D.).

Halecium plumosum, Hincks.

Described by Mr. Hincks from an Irish specimen in the collections of Trinity College, Dublin. It has apparently not been noticed since.

VII. SERTULARIIDÆ.

Sertularella polyzonias, Linn.

Found in abundance all round the coasts.

Sertularella Gayi, Lamouroux.

Birterbuy Bay, Connemara (G. S. Brady) ; Dublin Bay.

Sertularia rugosa, Linn.

South-west of Galley Head (1893) ; Bundoran, Donegal Bay (J. E. D.).

Diphasia rosacea, Linn.

Plentiful at most stations.

Diphasia attenuata, Hincks.

Dublin Bay (1886) ; south-west of Galley Head (1893).

Diphasia fallax, Johnston.

South-west of Galley Head, from a depth of 43 fathoms (1893).

Diphasia pinaster, Ell. and Sol.

Belfast Bay (Hyndman) ; Dublin Bay (W. Thompson) ; Giants' Causeway (Hassall).

Diphasia tamarisca, Linn.

South-west of Galley Head (1893) ; rare in Dublin Bay (Hassall).

Diphasia alata, Hincks.

South-west of Galley Head (1893).

Sertularia pumila, Linn.

Abundant everywhere.

Sertularia gracilis, Hassall.

Birterbuy Bay ; Blacksod Bay ; Casheen Bay, growing on *Fucus* (R. D. S.) ; Cork Harbour (Haddon) ; Laytown (1894 *a*).

Sertularia operculata, Linn.

Very plentiful, especially on *Laminaria* washed ashore.

Sertularia filicula, Ell. and Sol.

Irish coasts (W. Thompson).

Sertularia abietina, Linn.

Obtained from most dredgings, with numerous other zoophytes growing parasitically.

Sertularia cupressina, and *var.* argentea, Linn.

Dredged from most localities. Colonies of this species, sufficient to fill several large jars, were obtained from Lough Swilly by the Royal Dublin Society's Survey, with numerous other zoophytes upon them.

Hydrallmania falcata, Linn.

Trawled and washed ashore in great abundance.

Thuiaria thuja, Linn.

A rare Irish form. Recorded in the Dublin Bay list.

Thuiaria articulata, Pallas.

Dublin Bay (Ellis); north of Ireland (W. Thompson).

VIII. PLUMULARIIDÆ.

Antennularia antennina, Linn.

Dredged from numerous localities.

Antennularia ramosa, Lamarck.

Generally distributed.

Aglaophenia pluma, Linn.

Known from different spots all round the coast.

Aglaophenia tubulifera, Hincks.

Small portions attached to the body and limbs of *Stenorhynchus*, Blacksod Bay (R. D. S.).

Aglaophenia pinnatula, Ell. and Sol.

One of the numerous collections made by M'Calla from Roundstone, Galway; also collected by Miss M. Ball from Youghal, profusely investing about six inches of the stem of *Laminaria digitata*. Mr. Hincks says that Miss Ball's remarkable specimens have supplied the principal cabinets in the country.

Plumularia pinnata, Linn.

Collected from many parts of the coast.

Plumularia setacea, Ellis.

A common species

Plumularia Catharina, Johnston.

On worm-tubes from Ballycotton, depth 30 fathoms (R.D.S.); Arran Island (Barlee); Dublin Bay (J. E. D.); south-west of Galley Head (1893).)

Plumularia echinulata, Lamarck.

An abundant species in the shallow waters of the west coast. Bantry Bay (R. D. S.); plentiful on *Chorda filum*, Roundstone; Dublin Bay (J. E. D.).

Plumularia similis, Hincks.

Donaghadee (Hyndman); on *Fucus*, Berehaven; Dublin Bay (J. E. D.).

Plumularia halecioides, Alder.

On the appendages of *Stenorhynchus*, Berehaven (1893); "Argo" Cruise (1891).

Plumularia frutescens, Ell. and Sol.

Dublin Bay (Hassall); south of Ireland.

REFERENCES.

1841*a*. HASSALL, A. HILL, "Catalogue of Irish Zoophytes." Ann. Mag. Nat. Hist., vol. vi.

1841*b*. HASSALL, A. HILL, "Supplement to a Catalogue of Irish Zoophytes." Ann. Mag. Nat. Hist., vol. vii.

1856. THOMPSON, W., "Natural History of Ireland."

1859. ALLMAN, G. J. Ann. Mag. Nat. Hist.

1863. ALLMAN, G. J., "Notes on the Hydroida." Ann. Mag. Nat. Hist.

1864. ALLMAN, G. J., "Notes on the Hydroida." Ann. Mag. Nat. Hist., May, July.

1868. HINCKS, T., "British Hydroid Zoophytes."

1872. ALLMAN, G. J., "Gymnoblastic or Tubularian Hydroids," vol. ii.

1878. MACKINTOSH, H. W., "Hydroida." Brit. Assoc. Guide to the City and County of Dublin.

1886. HADDON, A. C., "Preliminary Report on the Fauna of Dublin Bay." Proc. Roy. Irish Acad., 2nd ser., vol. iv., Science.

1889. KIRKPATRICK, R., "Deep-Sea Trawling Expedition off the S. W. Coast of Ireland." Ann. Mag. Nat. Hist.

1891. HERDMAN, W. A., "Biological Results of the Cruise of the S. Y. 'Argo' round the West Coast of Ireland, 1890." Trans. Biol. Soc., Liverpool, vol. v.

1893. DUERDEN, J. E., "Report on the Hydroida collected by the Royal Irish Academy Survey off the S. W. Coast of Ireland, 1885, 1886, 1888." Proc. Roy. Irish Acad., 3rd ser., vol. iii.

1894.   THORNLEY, L. R., "Supplementary Report upon the Hydroid
         Zoophytes of the L. M. B. C. District."   Trans. Biol. Soc.,
         Liverpool, vol. viii.

1894*a*. DUERDEN, J. E., "Hydroids and Polyzoa collected between Lay-
         town and the Mouth of the Boyne."   Irish Naturalist, vol. iii.,
         No. 8.

1894*b*. DUERDEN, J. E., "Notes on the Marine Invertebrates of Rush,
         Co. Dublin."   Irish Naturalist, vol. iii., No. 2.

1895.   DUERDEN, J. E., "Survey of Fishing Grounds West Coast of
         Ireland, 1890–91.   Notes on the Hydroids and Polyzoa."
         Proc. Roy. Dub. Soc., vol. viii. (N. S.).

LII.

THE DISTRIBUTION OF DRIFT IN IRELAND IN ITS
RELATION TO AGRICULTURE. By J. R. KILROE,
(formerly) F.C.S., H. M. Geological Survey. (Plate XV.)

THE interest which your Society has for a long time taken, and
is taking, in the advancement of agriculture, has earned wide-
spread and just recognition.   One of your commendable objects is
the encouragement of Science as applied to industrial purposes ;
and in consonance with this aim, I have the honour of laying
before you some remarks upon the distribution of Drift deposits in
Ireland in their relation to agriculture.   The subject of these
deposits is one which has frequently been dealt with since 1824
when Weaver first called attention to the limestone gravels of
Carlow, Wicklow, and Wexford.   Amongst the investigators who
have laboured in this field of inquiry may be especially mentioned
the Rev. Maxwell Close, whose exhaustive paper on the general
glaciation of Ireland appeared in 1866.   Since that time many
additional observations have been noted by the staff of the Geological
Survey, and appear in the official publications as well as in Professor
Hull's " Physical Geology," in Mr. Kinahan's " Geology of Ireland,"
and in papers by these and other authors, amongst whom may be
mentioned Professors Sollas and Cole, Mr. Praeger, and Members
of the Belfast Naturalists' Field Club.

Hitherto, however, the Drift has been treated of, in detail,
from a purely geological, rather than from an economic, standpoint ;
and the attention which agriculture imperatively demands and is
receiving at the present time, may warrant the application to that
industry of the information available in the above sources, parti-
cularly the maps and memoirs of the Geological Survey.

It has generally been assumed that the structure of the Earth's
crust under a country, and the consequent geographical disposition
of the strata, determine the nature of the superincumbent soils, and

enable one to forecast the degrees of natural fertility which should be expected in different localities. To a certain extent this hypothesis holds, but, in our latitudes at least, it is subject to considerable modification, which it is one purpose of this paper to define.

Few in this day will dispute that soils are derived from the solid rocks which form the crust. When, however, one examines the detritus (mingled clay, sand, stony particles, etc.) resulting from rock decay throughout the country, and finds materials obviously derived from limestone strata, overlying granite, as in parts of the county of Dublin, and covering Silurian grits, as in parts of Wicklow and Wexford; débris of metamorphic rocks over limestone in Sligo, and over granite in Donegal, etc., it is not unnatural that some would question whether the disposition of geological strata has any direct bearing upon the local character of their earthy covering. Nor are such questions confined to the uninstructed. The lucid and well-informed author of a work on the "Principles of Land Valuation,"[1] signing himself "Aleph," apropos of this, says: "The relation between the soils and the underlying rocks is such, that any classification of the rocks, as, for instance, the division of the limestone into four descriptions, can be of no agricultural importance whatever." The circumstances alluded to are, I believe, to be accounted for by transplacement of rock detritus, which have obtained on a grand scale through the agency of land ice, and possibly of icebergs ; and such departure from what may be regarded as the natural order of things, has been attended with marked advantages to the agricultural interest, such as—

(1). A greater extension than would otherwise obtain of fertilizing materials.

(2). A mixing of materials drawn from different sources, which generally conduces to fertility.

The transplacements mentioned above have resulted in the present distribution of soils and subsoils, which we may speak of combinedly as *Drift*; and in this aggregate view of it we may conceive of an extensive covering made up of a confused mixture of stones and earth, robing two-thirds of the country or more;

---

[1] E. Ponsonby, Dublin, p. 68.

lying chiefly in the low grounds, where, however, the naked rock frequently presents itself over small areas; and in places rising to heights of 1350 or 1400 feet[1] on hill sides, softening the asperities of contour, and otherwise modifying the landscape.

Above the 1500 feet contour line extends an area of some 800 square miles, which may be regarded as waste mountain land. About 836 square miles between the 1500 feet and 1000 feet contours, contain very little Drift, well-nigh all the Drift falling below the latter contour, where it covers a large portion of the 30,836 square miles,[2] between this contour and the sea, probably over 20,000 square miles, including portions concealed by bog. This is shown by stippled dots on the published one-inch map of the country, which is accompanied by Explanations, containing general descriptions of the Boulder-clays. Detailed descriptions, however, are not published, though notes are given on the unpublished six-inch maps (which may be seen by the public at the Geological Survey Office), describing the superficial drift in many places: and such notes are of great value from an agricultural point of view; for fertility in Drift-covered areas is more dependent upon the character of the transported materials than on the nature of the rock which they conceal, and for the representation of which alone colouring is used on the published map. Mr. Albert Pell says, in the Journal of the Royal Agricultural Society of England (Part I. 1890) with reference to this subject: "It is with the surface that the farmer has to do. A geological El Dorado of fertility may be below him at a depth of 4 feet; but if the space between that and the sole of his plough, or the hoof of his live-stock, be taken up by a layer of Boulder-clay, it might as well be on the other side of the world, for all the good that it will do him." A map which would be likely to meet the requirements should indicate the superficial drift which forms the soil, and in most cases the subsoil, by light tints of colour, decided by the materials of which the Drift is chiefly composed, heavier tints being appropriated to areas of uncovered rock. The light tints might be lined diagonally to represent a different

---

[1] Rev. M. Close records the occurrence of transported blocks on the Dublin mountains, at a height of 1760 feet. See Paper Jour. Roy. Geological Society, Ireland, vol. for 1866, p. 10.

[2] Ascertained by the Ordnance Survey Staff for Sir R. Kane.

Boulder-clay beneath, when such is known to exist. The addition of letters, descriptive of the nature of the soil in each locality, and numbers attached to the letters to indicate the depth at which a marked change takes place in the subsoil, would supply all the information reasonably demanded on a good agricultural map.

The small map accompanying this paper is on too minute a scale to show the different kinds of drift: its object is to represent the drift-covered areas, and those in which the rock of different formations is seen.

To illustrate the nature of such information, and the great variety assumed by the detritus met with throughout the country, I have been enabled to make a collection of soils and boulder-clays from different places, and examinations of the same. The method adopted in the examinations is described in detail at the end of the paper, where also the results appear in tabulated form. It will, I think, be admitted that detailed information of this character is a necessity, if the cultivator is to be placed fully and intelligently in touch with the geology of the country, and if the resources of the soil are to be turned to the best account. In any endeavour to stimulate and foster local effort, by technical instruction or otherwise, attention scientifically directed to the nature and properties of soils could not fail to prove advantageous. Agriculturists would become more intelligently aware of the deficiencies of the soil, and how best to meet them ; of the resources naturally available therein, and how best to profit by them. Indeed any system of agriculture planned upon economic lines, and assuming to be in any sense perfect, must give Geology a prominent place—a fact which claims recognition in the operations of an Agricultural Board.

Referring to a geological map of Ireland, it will be observed that Carboniferous limestone occupies a large tract forming the central plain. Grits, shales or slate of the Carboniferous, Old Red Sandstone, and Silurian formations also cover large districts; mica-schists and quartzite, which are metamorphosed shales and grits, occur extensively in Londonderry, Mayo, and Galway. We also find igneous rocks of different ages, which penetrate and overlie the sedimentary rocks mentioned. These are divisible into acid, basic, and intermediate groups, according as they contain a greater or smaller quantity of silica. The chief consideration

regarding rocks, in the agricultural point of view, is their chemical composition, seeing it is from this that the elements of natural fertility must be drawn.

Soil, earth, or "clay," as known to the agriculturist, consists of a mixture of pure clay (hydrated silicate of alumina), usually with finely-divided felspar, or felspathic mud, undecayed rock particles, small stones, and more or less organic matter or *humus* (*i.e.* decayed vegetable and animal substances). If the stony particles were entirely withdrawn, and the impalpable mud or *clay* only were used for plant growth, it would soon become exhausted of whatever mineral nutrients it contained. The stony particles and fragments contain the stock supplies of fertilizing minerals. They are constantly undergoing decomposition in the field by oxidation and solution, owing to which their enriching elements are transferred to the clayey matrix.[1] An observant person, noting the stony contents of a soil, may form a fair judgment of the chemical constituents he may count upon in it —a course which will direct him, in the absence of chemical analyses, towards the most advantageous selection of manures. Here, also, we find the reason of the well-known advantages attaching to rotation cropping. Crop after crop of the same kind, which would draw most largely upon one or two minerals in the soil, would exhaust the *storehouse* of these minerals; while a rotation of crops gives time, before the same crop is repeated, for the replenishment of the storehouse at the expense of the stony particles.

Soils derived severally from the rocks upon which they rest would rarely possess all the constituents essential to fertility. Those formed by the disintegration of acid igneous rocks, granites, felsites, &c., felspathic grits, sandstones, quartzite, shale, slate, and mica-schist would lack or be deficient in several important ingredients such as lime; while those derived from basic igneous rocks, basalt, dolerites, diorites, serpentines, &c., limestone, and calcareous grits will be deficient in potash.

The celebrated fattening lands of Meath and North Kildare—

---

[1] The matrix possesses the notable property of absorbing the leading manurial substances—phosphoric acid, potash, lime, magnesia, and soda, as well as ammonia. It therefore serves as a convenient storehouse wherein nutriment is temporarily laid up in available form for crops.

" the richest soil " which Wakefield " ever saw turned up with plough "—are over limestone, but being drift soil it is usually deep, and contains an admixture of other rock débris.[1]   The beneficial effects accompanying the intermingling of various kinds of rock detritus is dwelt upon by Dr. Fream,[2] who points out that the most fertile veins of land in England follow the junction of different geological formations.   In our own country the proverbial fertility of the Golden Vein in Tipperary and Limerick is doubtless due to the mingling of materials derived from the Silurian and Old Red Sandstone hills, the Galtees and Slieve Phelim on either side, with those derived from the limestone of the valley, as well as from the acid and basic igneous rocks which there penetrate the limestone.

The Glacial deposits of Ireland are distinguishable as Upper and Lower Boulder-clays, both of which are frequently to be met with in the same section, and inter-glacial beds, which are stratified sands and gravels occasionally to be seen between the two Boulder-clays.   These beds, known as " Middle Sands and Gravels," though frequently covered with Upper Boulder-clay, are not often to be observed resting upon the Lower ; and in many cases they may be regarded as washed or rearranged representatives of the latter Boulder-clay.   Throughout wide tracts over the central plain, and on the flanks of the Dublin and Wicklow mountains, they form the surface; in which case the soil is gravelly and porous.   The Upper Boulder-clay also frequently yields a porous soil, being often rudely stratified, and containing layers of sand.   The Lower clay not only is now of great thickness in many places, as may be seen in each of the four provinces, but seems at one time to have had a very wide extension over the country.   In very many places it is seen to consist chiefly of limestone débris, drawn probably from the great central plain ; and to this fact must be attributed the fertility of the country on each side of the Leinster granite range, where the limestone drift covers some 500,000 acres of Dublin, Wicklow, Wexford, Waterford, Carlow, and Kilkenny. The solid crust is there formed of Silurian and other rocks equally incapable of yielding so fruitful a soil.   The same may be said of

---

[1] See Nos. 1–9 in the Table at the end.
[2] " Soils and their Properties," pages 104, 105.

the fertile district skirting Bantry Bay, where a thick deposit of Limestone Boulder-clay is to be found, and of the country stretching north-eastward by Newbliss in the county of Monaghan, where a good soil rests upon unpropitious Silurian rock.

An advantage, which should not be lost sight of, attaches to the transportation of limestone débris to areas where it does not form part of the solid crust, namely the abundant supply of limestone boulders, for burning for agricultural and other purposes, which is readily procurable from the deeper portions of the drift in such places.

Nutriment may be drawn from considerable depths by such plants as lucern and sainfoin; and, through capillarity, fertilizing constituents in solution may be placed within reach of ordinary plants; yet it is manifest that ordinary herbage and rotation crops are mostly dependent upon the uppermost two or three feet of the soil and subsoil. A layer of clay, therefore, which might be overlooked in deep sections of drift, may, to the agriculturist, be a matter of prosperity or the reverse.

As a general rule the uppermost layer of clay, even when it rests upon another Boulder-clay, is derived chiefly from the rocks of the immediate locality, which appear here and there through the drift—mingled with material derived from the Lower clay, and those carried from higher grounds adjoining. This will be seen by reference to soils and subsoils at Rathdrum, Glenealy, Baltinglass; and at other localities, also mentioned in the table, in the counties of Tyrone and Fermanagh.

In many places, especially in the higher grounds, the soils and subsoils have doubtless been formed by the disintegration of rock *in situ;* and it becomes difficult to say where this runs into true drift. The latter is easily recognizable, however, when it rests (1) upon a glaciated surface; or (2) upon a Lower Boulder deposit; or when it is (3) intermingled with foreign rock detritus, or (4) contains glaciated boulders.

I add a few remarks upon the appended Table. In estimating the proportion of stones in a soil, with a view to the preparation of such a Table, to reckon only the boulders does not give a true idea of the soil contents; for numerous small fragments affect its character, it is needless to say, more than a few large ones; and the frequent occurrence of boulders of a certain kind does not

necessarily indicate an abundance of small fragments of the same kind of rock. A general estimate therefore could alone be given; and comparative abundance, which partly depends upon the sizes of the fragments selected for reckoning, is indicated by the numbers 1, 2, 3, 4, 5, according as the species of rock heading a column, is occasionally, commonly, abundantly, very abundantly, or, almost solely, represented. In giving the results as to carbonate of lime, also, the same numbers are used with similar intent, without aiming at strict statement of quantitative results.

Samples of clays, about 2 lbs. in weight, including pebbles, as they naturally occurred therein, were procured from the different places named in the Table. Soils and sub-soils, or Upper and Lower clays, from each locality, were taken at the same point, geographically. All were perfectly dried in the air, and at a low oven-heat, and weighed. They were then sifted through wire netting of about $\frac{3}{16}$th-inch mesh, so as to separate all fragments of such a size as to admit of safe determination. These were well rubbed with the fingers over the sieve, so as to remove all clay adhering to them, and examined with the aid of a lens, after being washed, dried, and cracked with a hammer, so as to expose fresh surfaces. Little difficulty was experienced in classifying and arranging them in the various lithological groups set forth in the Table.

The materials which went through the sieve were again sifted through wire netting of $\frac{1}{16}$th-inch gauge. The gravel which lay on the sieve was rubbed between the fingers, and lightly triturated in a mortar, until no small lumps of clay remained. This was resifted, and all the clay and fine sand which passed through weighed, to ascertain the percentage of their aggregate in the samples.

The relative quantities of carbonate of lime in the samples was ascertained by treating the finer gravel and coarse sand with cold hydrochloric acid, diluted with about an equal quantity of water. The comparative amount present in each case was judged by the degree of effervescence caused by the escaping carbonic acid gas.

It will be noticed, on examining the Table, that soils in limestone districts are not very calcareous, though they might be expected to be so. Chert (appearing in the columns under the head of quartz) is to be frequently met with in soils over limestone,

limestone boulder-clays, and gravels; and this substance is known to have been embedded in limestone. The latter material therefore seems to have been dissolved away, possibly to a great extent since the porous Upper clays were deposited, leaving the but slightly soluble chert. Blocks and pebbles of "rottenstone," after calcareous grits and shale, also occur abundantly in the Upper clays, with scarcely any calcareous matter remaining. This dissolving out of calcareous matter from the soil of Ireland has been hastened probably by cultivation, but is doubtless due chiefly to the humidity of the climate.

[TABLE OF SOILS, SUB-SOILS, ETC.

ABBREVIATIONS.—L. = loam; S. = subsoil; D. = drift; U. C. = Upper Boulder-cla

    L. C. = Lower Boulder-clay; G. = gravel; s. = sandy; g. = gray; y. = yello

    r. = red; b. = brown; l. = light; d. = dark; 1, 2, 3, 4, 5 comparative abu

    dance,—5 being maximum.

No.	Sample.	Subjacent rock.	Locality.	County.	Geol Inch
1	y. b. L., . .	—	Dunboyne, . .	Meath, .	1
2	y. S., . .	—	,,	,, .	
3	y. U. C., . .	—	S. of Dunboyne, .	,, ,	1
4	d. g. L. G., . .	Limestone, .	,, ,, .	,, .	
5	y. U. C., . .	—	Lucan, . . .	Dublin, .	
6	d. g. L. G., . .	Limestone, .	,, . : .	,, .	
7	b. s. L., . .	—	Skerries, . .	,, .	1
8	b. S. (10 ft. below), .	Limestone, .	,, . .	,, .	
9	y. U. C. . .	,, .	Sallins, . . .	Kildare, .	1
10	l. b. s. L., . .	—	Cabra, Kells, . .	Meath,	
11	y. g. U. C. . .	Grit and slate, .	,, ,, .	,, .	
12	b. U. C., . .	—	Greystones, .	Wicklow, .	1
13	d. g. L. C., . .	Grit and slate, .	,, .	,, .	
14	b. s. L., . .	—	Grange Con, .	,, .	1
15	S., . . .	—	,, ,, .	,, .	
16	L. G. (20 ft. below), .	Grit and slate, .	,, ,, .	,, .	
17	y. b. U. C., . .	,, ,, .	Glenealy, .	,, .	1
18	Drift, . .	,, ,, .	Rathdrum, .	,, .	1
19	l. g. U. C., . .	—	Kilsallagh, .	Mayo, .	
20	d. g. L. C., . .	Mica-schist, .	,, .	,, .	
21	y. s. U. C., . .	—	Near Westport, .	,, .	
22	d. g. L. C., . .	Limestone, .	,, ,, .	,, .	
23	l. b. s. L., . .	—	,, Newport, .	,, .	
24	y. s. U. C., . .	—	,, ,, .	,, .	
25	d. g. L. C., . .	Limestone, .	,, ,, .	,, .	
26	y. U. C., . .	—	S. of Castlebar, .	—	
27	b. U. C., . .	—	W. of Kilboyne, .	Mayo, .	
28	l. b. L. C., . .	Limestone, .	,, ,, .	,, .	
29	d. b. D. (surface), .	,, .	At Kilboyne, .	,, .	
30	,, ,, .	,, .	Manulla, .	,, .	
31	s. D., . .	O. R. S., .	W. of Castlebar, .	,, .	
32	y. U. C., . .	Limestone, .	Aghagad, . .	Roscommon,	
33	y. U. C., . .	,, .	,, .	,, .	
34	L. G., . .	Limestone, .	,, .	,, .	
35	y. b. U. C. = S., .	—	Castlecoote, .	,, .	
36	y. L. G., . .	Limestone, .	,, .	,, .	
37	y. b. s. L., . .	—	Bantry, .	Cork, .	
38	y. U. C. = S., .	—	,, .	,, .	
39	d. g. L. C., . .	Grits and slate, .	,, .	,, .	
40	y. U. C., . .	—	Derryvree, .	Fermanagh,	
41	d. b. g. L. C., .	Limestone, .	,, .	,, .	
42	r. b. D., . .	,, .	1 mile S. of Lisbellaw, .	,, .	
43	y. U. C., . .	—	Omagh, . .	Tyrone, .	
44	d. g. L. C., . .	Limestone, .	,, .	,, .	
45	r. D., . .	O. R. S., .	¾ mile S. of Omagh, .	,, .	
46	y. b. U. C., . .	—	Newbliss, . .	Monaghan,	
47	d. g. L. C., . .	Grits and slates, .	,, .	,, .	
48	g. D., . .	Granite, . .	Baltinglass, .	Wicklow, .	
49	s. D., . .	Grits and slates, .	Ballinhassig, .	Cork, .	

Contents.		Rock Fragments and Boulders.								
centage.		Potash-Alumina-Silica Group.					Lime-Phosphate-Magnesia Group.		
Coarse sand and gravel.	Comparative quantity of carbonate of lime.	Acid igneous rocks.	Felspathic grit.	Sandstone, grit, and quartzite.	Quartz & chert.	Shale slate and mica-schist.	Basic igneous rocks.	Limestone.	Calcareous grit and shale.
—	2	—	—	3	3	—	—	1	3
—	2	—	—	3	3	—	—	1	3
—	2	—	—	3	2	—	—	—	3
—	5	—	—	—	1	—	—	5	2
—	3	—	—	3	1	—	—	2	3
—	4	—	1	—	2	—	—	4	3
35	3	—	2	3	1	2	—	2	3
70	3	3	2	3	1	1	2	2	2
30	2	—	—	3	—	—	—	2	3
50	—	—	3	3	1	3	—	—	1
63	1	—	3	3	1	3	—	—	2
53·6	2	3	2	3	1	2	—	2	2
—	5	1	2	2	—	—	—	4	—
47	1	—	—	4	—	2	—	—	2
51	3	—	—	3	—	1	—	3	2
89·7	5	—	—	3	—	1	—	4	1
39	1	2	2	4	—	1	—	—	—
71	—	—	—	—	1	4	—	—	—
41	—	—	—	3	2	—	3	—	—
48	3	—	—	2	2	2	3	3	2
29	—	1	2	3	2	2	1	—	—
37	4	—	—	3	—	1	—	4	—
16	—	1	—	5	1	—	—	—	—
26·2	—	1	—	4	1	1	—	—	—
50	4	1	—	2	—	—	—	5	—
20	3	—	—	5	—	—	—	—	2
21	2	—	—	5	1	—	—	—	2
43	5	—	—	2	1	1	—	5	—
41·2	5	—	—	1	1	—	—	5	—
54	5	—	—	—	1	—	—	5	—
42	1	1	3	4	1	—	—	—	—
43·5	1	—	—	4	1	—	—	—	3
29	3	—	—	4	—	—	—	3	—
—	5	—	—	1	—	—	—	5	—
25	1	—	—	3	2	—	—	1	—
50	5	—	—	2	1	—	—	5	—
36	2	—	1	3	—	2	—	1	1
27	1	—	—	3	—	2	—	—	1
50	4	—	—	2	1	3	—	4	2
7	1	—	—	4	1	—	—	1	—
29	4	1	—	3	1	1	—	3	—
40	3	—	—	3	1	1	—	3	—
38	1	—	2	3	1	2	—	—	—
63	5	1	—	—	1	1	—	4	2
51	2	—	—	4	1	1	—	—	—
—	3	—	—	4	1	—	—	2	—
53	4	—	2	3	1	1	—	3	—
32	1	3	—	3	1	2	2	2	—
71	—	—	—	5	—	2	—	—	—

TABLE SHOWING NATURE OF SOILS, SUBSOILS AND BOULDER CLAYS IN VARIOUS PLACES.

ABBREVIATIONS.—L. = loam; S. = subsoil; D. = drift; U. C. = Upper Boulder-clay; L. C. = Lower Boulder-clay; G. = gravel; s. = sandy; g. = gray; y. = yellow; r. = red; b. = brown; l. = light; d. = dark; 1, 2, 3, 4, 5 comparative abundance.—5 being maximum.

No.	Sample	Subjacent rock	Locality	County	Geological Inch Sheet	Contents Percentage — Fine sand, clay, and humus	Coarse sand and gravel	Comparative quantity of carbonate of lime	Potash-Alumina-Silica Group — Acid igneous rocks	Felspathic grit	Sandstone, grit, and quartzite	Quartz & chert	Shale slate and mica-schist	Lime-Phosphate-Magnesia Group — Basic igneous rocks	Limestone	Calcareous grit and shale
1	y. b. L.,	—	Dunboyne,	Meath,	101	—	—	2	—	—	3	3	—	—	1	3
2	y. S.,	—	„	„	101	—	—	2	—	—	3	3	—	—	1	3
3	y. U. C.,	—	S. of Dunboyne,	„	111	—	—	2	—	—	3	2	—	—	—	3
4	d. g. L. G.,	Limestone,	„	Dublin,	„	—	—	5	—	—	1	—	—	—	5	2
5	y. U. C.,	—	Lucan,	„	„	—	—	3	—	—	3	1	—	—	2	3
6	d. g. L. G.,	Limestone,	„	„	102	—	—	4	—	1	—	2	—	—	4	3
7	b. s. L.,	—	Skerries,	„	„	65	35	3	—	2	3	1	2	—	2	3
8	b. S. 10 ft. below),	Limestone,	„	„	102	30	70	3	3	2	3	1	1	2	2	2
9	y. U. C.,	„	Sallins,	Kildare,	119	70	30	2	—	—	3	—	—	—	2	3
10	l. b. s. L.,	—	Cabra, Kells,	Meath,	90	50	50	—	—	3	3	1	3	—	—	1
11	y. g. U. C.,	Grit and slate,	„	„	„	37	63	1	—	3	3	1	3	—	—	2
12	b. U. C.,	—	Greystones,	Wicklow,	121	46·4	53·6	2	—	3	3	1	2	—	2	2
13	d. g. L. C.,	Grit and slate,	„	„	„	5	—	5	1	2	2	—	—	—	4	—
14	b. s. L.,	—	Grange Con,	„	129	51	47	1	—	—	4	—	2	—	—	2
15	S.,	—	„	„	„	49	51	3	—	—	3	—	1	—	3	2
16	L. G. (20 ft. below),	Grit and slate,	„	„	„	10·3	89·7	5	—	—	3	—	1	—	4	1
17	y. b. U. C.,	„ „	Glenealy,	„	130	61	39	1	2	2	4	—	1	—	—	—
18	Drift,	„ „	Rathdrum,	„	130	29	71	1	—	—	—	1	4	—	—	—
19	l. g. U. C.,	—	Kilsallagh,	Mayo,	74	59	41	—	—	—	3	2	—	3	—	—
20	d. g. L. C.,	Mica-schist,	„	„	„	52	48	3	—	—	2	2	2	3	3	2
21	y. s. U. C.,	—	Near Westport,	„	„	71	29	—	1	2	3	2	2	1	—	—
22	d. g. L. C.,	Limestone,	„ „	„	„	63	37	4	—	—	3	—	1	—	1	—
23	l. b. s. L.,	—	„ Newport,	„	„	84	16	—	1	—	5	1	—	—	—	—
24	y. s. U. C.,	—	„ „	„	„	72·8	26·2	—	1	—	4	1	1	—	—	—
25	d. g. L. C.,	Limestone,	„ „	„	75	50	50	4	1	—	2	—	—	—	5	—
26	y. U. C.,	—	S. of Castlebar,	—	75	80	20	3	—	—	2	—	—	—	—	2
27	y. U. C.,	—	W. of Kilboyne,	Mayo,	75	79	21	2	—	—	5	1	—	—	—	2
28	l. b. l. C.,	Limestone,	„ „	„	„	57	43	5	—	—	2	1	1	—	5	—
29	d. b. D. (surface),	„	At Kilboyne,	„	„	58·8	41·2	5	—	—	1	1	—	—	5	—
30	„ „	„	Manulla,	„	„	46	54	5	—	—	—	1	—	5	—	—
31	s. D.,	O. R. S.,	W. of Castlebar,	Roscommon,	87	58	42	1	1	3	4	1	—	—	—	—
32	y. U. C.,	Limestone,	Aghagad,	„	„	56·5	43·5	1	—	—	4	1	—	—	—	3
33	y. U. C.,	„	„	„	„	71	29	3	—	—	4	—	—	—	3	—
34	L. G.,	Limestone,	„	„	„	—	—	5	—	—	1	—	—	—	5	—
35	y. b. U. C. = S.,	—	Castlecoote,	„	„	75	25	1	—	—	3	2	—	—	1	—
36	y. L. G.,	Limestone,	„	Cork,	199	50	50	5	—	—	2	1	—	—	5	—
37	y. b. s. L.,	—	Bantry,	„	„	64	36	1	—	1	3	—	2	—	1	1
38	y. U. C. = S.,	—	„	„	„	73	27	1	—	—	3	—	—	—	—	1
39	d. g. L. C.,	Grits and slate,	Derryvree,	Fermanagh,	45	50	50	4	—	—	2	1	3	—	4	2
40	y. U. C.,	„	„	„	„	93	7	1	1	—	4	1	—	—	1	—
41	d. b. g. L. C.,	Limestone,	1 mile S. of Lisbellaw,	„	33	71	29	4	—	—	3	1	1	—	3	—
42	r. b. D.,	„	Omagh,	Tyrone,	„	60	40	3	—	2	3	1	1	—	3	—
43	y. U. C.,	—	„	„	„	62	38	5	1	—	3	1	2	—	—	—
44	d. g. L. C.,	Limestone,	1 mile S. of Omagh,	„	„	37	63	2	—	—	1	1	1	—	1	2
45	r. D.,	O. R. S.,	Newbliss,	Monaghan,	58	49	51	3	—	—	4	1	1	—	—	—
46	y. b. U. C.,	—	„	„	„	47	53	4	—	2	4	1	—	—	2	—
47	d. g. L. C.,	Grits and slates,	Baltinglass,	Wicklow,	129	68	32	1	3	—	3	1	1	—	3	—
48	g. D.,	Granite,	Ballinhassig,	Cork,	194	29	71	—	—	—	3	1	2	2	2	—
49	s. D.,	Grits and slates,	„	„	„	—	—	—	—	—	5	—	2	—	—	—

LIII.

NOTE ON THE WORM ASSOCIATED WITH *LOPHOHELIA PROLIFERA*. By FLORENCE BUCHANAN.

SHORTLY after the publication of the Report on the Deep-Sea Polychæta obtained during the Royal Dublin Society's Survey off the West Coast of Ireland,[1] wherein I described, as a new species, *Eunice philocorallia*, a worm inhabiting colonies of *Lophohelia prolifera*, the late Mr. George Brook kindly drew my attention to the mention of a similar worm, inhabiting this coral, by Bishop Gunnerus, in 1768,[2] who refers to it as the *Nereis madreporæ pertusæ*.[3] Seeing that later writers, Malmgren[4] and others, had identified the *Nereis madreporæ pertusæ* of Gunnerus with *Leodice norvegica*, L., and having ascertained, by comparison with type specimens of the latter species kindly sent me for the purpose by Dr. Armauer Hansen, that the Irish specimens were not *Leodice* (or rather *Eunice*[5]) *norvegica*, L., I concluded that I was still justified in having given a new specific name, although I should, probably, have referred the *N. madreporæ pertusæ* of Gunnerus to it. I have, however, recently come across a Paper[6] in the K. Norske Selsk. Skr. for 1880, in which the author, V. Storm, makes a new species, which he calls *Leodice gunneri*, for the *Nereis madreporæ pertusæ* of Gunnerus and the *L. norvegica*, auct. I have no doubt, from his description, and from the examination of the inhabitants of some *Lophohelia* colonies dredged off the Norwegian

---

[1] This Journal, vol. VIII., Part II., No. 15. Cf. also '' Branched Worm-tubes and Acrozoanthus,'' by Prof. A. C. Haddon, vol. VIII., Part IV., p. 344.

[2] K. Norske Vid. Selsk. Skr. Throndhjem, 1768, pp. 50–51, Pl. ii.

[3] *Madrepora pertusa* is the old name for *Lophohelia prolifera*.

[4] Malmgren. Annulata Polychæta. Öfvers. K. Vet-Ak. Förh., 1867, p. 190.

[5] There is no distinction between the genera *Leodice* and *Eunice*.

[6] Storm V. Bidrag til Kundskab om Throndhjemsfjordens Fauna. K. Norske Vid. Selsk. Skr., 1880, pp. 92–95.

coast by Professor Lankester and kindly lent me by him, that Storm had before him the same worm as I have named *Eunice philocorallia*, and I would therefore withdraw my name of *Eunice philocorallia* in favour of his *Eunice gunneri*.

Dr. E. von Marenzeller[1] described in the same year as myself a *Eunice* inhabiting the *Lophohelia prolifera* colonies of the Mediterranean; and he refers his specimens to the *Eunice floridana* of Ehlers which I had mentioned as being the species most nearly allied to my *Eunice philocorallia*. He had only two imperfect specimens before him; and it seems to me that what differences there are between his specimens and mine are such as might occur between individuals of the same species. I hope that he will agree with me in referring his *Eunice floridana* to the *Eunice gunneri*, Storm. If he is right in identifying the species with the *E. floridana* of Ehlers,[2] then this must be regarded as a second synonym of *E. gunneri*, and we have the following synonymical table :—

Eunice gunneri, Storm.

> *Nereis* madreporæ pertusæ (*N.* norvegica) Gunnerus, 1768.
> *Leodice norvegica*, auct. *ex parte.* (non *L. norvegica*, L.)
> *Leodice gunneri*, Storm. 1880.
> (?) *Eunice floridana*, Ehlers, 1887.
> *Eunice philocorallia*, Buchanan, 1893.
> *Eunice floridana*, v. Marenzeller, 1893.

It only remains for me to apologize to Science for having contributed to the long list of unnecessary specific names.

---

[1] Denkschr. Ak. Wien. lx. Ber. Comm. Erforsch. östl. Mittelm., pp. 31–33, Pl. ii., f. 5.

[2] For my own part I would leave the *Eunice floridana*, Ehl., for the present, as a distinct species. I do not feel certain of its identity with the inhabitant of the *Lophohelia* colonies.

LIV.

ON SOME DRAGONFLIES IN THE DUBLIN MUSEUM OF SCIENCE AND ART. By GEORGE H. CARPENTER, B.Sc., Lond., Assistant Naturalist in the Science and Art Museum, Dublin. (Plate XVI.)

Having recently, with the kind assistance of Mr. W. F. Kirby of the British Museum, named the dragonflies in the Dublin Museum collection, I find that we possess examples of at least two species which appear to be undescribed. It seems desirable, therefore, to publish descriptions and figures of these; they are both referable to the sub-family Libellulinæ. At the same time I take the opportunity of figuring and describing fully both sexes of an interesting species of Agrionid from Jamaica, which was founded forty years ago by the Baron de Selys-Longchamps on a single imperfect male specimen.

My best thanks are due to my friend, Mr. R. J. Mitchell, who has kindly photographed the wings of the two new species.

Family.—LIBELLULIDÆ.

Libellulinæ.

Genus.—MISAGRIA, Kirby.[1]

Misagria funerea, sp. nov.

(Pl. XVI., figs. 5–9.)

Male.—Length, 37 mm.   Expanse, 66 mm.   Pterostigma, 3·5 mm.

Head.—Face and mouth-parts yellow; clypeus and frontal tubercle, which is distinctly concave (fig. 5), bright metallic green;

---

[1] Trans. Zool. Soc. Lond. xii., 1889 (pp. 259, 296).

occiput, blackish. Thorax, dull black, somewhat reddish beneath ; abdomen, entirely shining black. Anal upper appendages (fig. 7), slender and curved at base, enlarged and truncated at apex, a little longer than lower appendage ; aperture of second segment bounded in front by a conical "hood," at sides behind by a pair of prominent lobes ; appendages rather large, terminating in small hooks pointed backwards (figs. 8, 9). Wings (fig. 6), hyaline, very slightly tinged with brown at base ; pterostigma, blackish ; forewings, with fourteen antecubital and ten postcubital nervures ; triangle followed by one row of three cells, then two ; hindwings, with eleven–twelve antecubital and ten–eleven postcubital nervures; lower basal cell with two nervures ; legs, black, with coxæ and insides of front femora yellowish.

Nicaragua.—(Coll. Miss Hamilton).

This species differs from *M. parana*, Kirby, the type of the genus in having the frontal tubercle bifid instead of convex, and the appendages of second segment much less conspicuous ; but, I think, the agreement in wing-neuration is sufficient to warrant its inclusion in the same genus. It may be readily separated from *M. parana* by its black colour and the smaller number of antecubital and postcubital nervures in both wings.

Genus.—ZYXOMMA, Rambur.[1]

Zyxomma multinervis, sp. nov.

(Pl. XVI., figs. 1–4.)

Male.—Length, 52 mm. Expanse, 85 mm. Pterostigma, 3 mm.

Head.—Face and sides of clypeus, yellow ; labrum, black ; mouth-parts brown ; centre of clypeus and frontal tubercle, black. Thorax and three basal segments of abdomen pruinose ; remainder of abdomen, shining black. Hinder lobe of the second segment rounded ; prominent aperture, bounded in front by large spherical "hood" ; appendages small, yellow, with recurved hooks (figs. 3, 4). Paired anal appendages as long as the two terminal segments ; nearly straight, evenly dilated at apex ; lower appendage

---

[1] " Insectes Neuropterès," Paris, 1842 (p. 30). Kirby, Cat. Neur. Odonata, Lond. 1890 (p. 35).

three-quarters as long, very broad at base ; upper edge, straight ;
lower edge, evenly rounded to a blunt point (fig. 2).   Legs, deep
brown to blackish ; coxæ and inside of femora, pruinose.   Wings
(fig. 1), hyaline, slightly touched with brown at base, infuscated
from inner edge of pterostigma to tip ; pterostigma, black ;
forewings, with 14–15 antecubital, and 11 postcubital nervures,
first four of the latter not continuous ; hindwings, with 10–11
antecubital, and 12–13 postcubital nervures.

Laloki river, British New Guinea (coll. Col. St. G. Smith).

This is, I believe, the first Zyxomma recorded from any part of
the Australian region.   *Z. petiolatum,* Rambur, the type-species
from India, has but 12 antecubital nervures in the forewing.
Z. obtusum, Alb.[1] from Sumatra, has 13 antecubitals, and only
7–9 postcubitals.   Its anal appendages also differ in form from
those of the present species.

<div style="text-align:center">

Family.—AGRIONIDÆ.

Coenagrioninæ.

Genus.—**TELEBASIS,** Selys[2] (Kirby[3]) (= *Erythagrion,* Selys[4]).

Telebasis macrogaster (Selys).

(Pl. XVI., figs. 10–15.)

</div>

This dragonfly was described by the Baron de Selys Long-
champs in 1857[5], under the name of *Agrion macrogaster,* from
a male which had lost its head, feet, and hinder abdominal
segments.   Later, the Baron, in his Synopsis of the Agrioninæ[6],
referred it, with doubt, to his genus *Leptobasis.*   There are, in the
British Museum collection, several specimens from Jamaica
referred, doubtless correctly, to this species, and with these agree
a male and two females in the Dublin collection.   Fortunately
some of the feet are preserved, and as they show small but distinct

---

[1] Veth's Midden-Sumatra, 1881 (Neuropt., p. 1).

[2] Bull. Acad. Belg. (2) xx., 1865 (p. 378).

[3] Cat. Neur. Odonata (p. 155).

[4] Bull. Acad. Belg. (2) xlii., 1876 (p. 955).

[5] Selys in Sagra's " Hist. Cuba " (Insectes, p. 465).

[6] Bull. Acad. Belg. (2) xliii. (p. 102).

accessory claws (fig. 10), the species cannot be retained in the genus *Leptobasis*. It must be transferred to that which the Baron de Selys Longchamps called first *Telebasis*, later *Erythagrion*, though it differs from the other species in the male, having the abdomen of a dark metallic bronze above, like the female, instead of a bright red.

Male.—Length, 45 mm. Expanse, 43 mm.

Head, dark bronze above and in front ; with orange transverse edge to occipital region ; pale behind and beneath. Thorax, orange ; pronotum, with central longitudinal dark stripe, spreading transversely on hinder lobe ; mesothorax, with central and lateral dark bronze stripes ; thorax, pale beneath. Abdomen, long and slender, dark bronze above, pale beneath ; hinder segments, entirely dark, nearly black ; appendages of the second segment (figs. 13, 14), very prominent and complicated ; central organ membranous, and recurved at its extremity ; a pair of palp-like structures directed backwards from the middle of second segment, and a pair of prominent, rather truncated, processes from hinder margin, projecting beyond third segment ; upper anal appendages much shorter than lower, stout and conical as viewed from above, truncated and depressed as viewed from side, brown in colour ; lower appendages, black, prominent, and forcipated (figs. 11, 12).

Female.—Length, 40 mm. Expanse, 42 mm.

In colour and markings closely resembling the male, but the terminal and abdominal segments are paler beneath ; these segments are greatly swollen, and bear two pairs of small appendages (fig. 15).

In the wings of both sexes, the quadrilateral has (as noted for the male by the Baron de Selys) the upper side two-fifths as long as the lower in the front pair, three-fifths in the hind pair, and the postcostal nervure is much farther from the first than from the second antecubital. The number of postcubitals in our specimens is twelve in the front, which it varies from nine to eleven in the hindwings.

EXPLANATION OF PLATE XVI.

Fig.

1. *Zyxomma multinervis,* . male; wings.

2.   ,,   ,,   . ,, terminal segments of abdomen, magnified.

3.   ,,   ,,   . ,, base of abdomen, magnified.

4.   ,,   ,,   . ,, ventral edge of second segment and appendages, more highly magnified.

5. *Misagria funerea,* . male; head, magnified.

6.   ,,   ,,   . ,, wings.

7.   ,,   ,,   . ,, terminal segments of abdomen, magnified.

8.   ,,   ,,   . ,, base of abdomen, magnified.

9.   ,,   ,,   . ,, ventral edge of second segment and appendages, more highly magnified.

10. *Telebasis macrogaster,* . claws of foot, magnified.

11.   ,,   ,,   . male; terminal segments of abdomen from above, magnified.

12.   ,,   ,,   . ,, terminal segments of abdomen from side, magnified.

13.   ,,   ,,   . ,, base of abdomen, magnified.

14.   ,,   ,,   . ,, base of abdomen, more highly magnified.

15.   ,,   ,,   . female; terminal segments of abdomen from side, magnified.

LV.

THE GEOGRAPHICAL DISTRIBUTION OF DRAGONFLIES.
By GEORGE H. CARPENTER, B. Sc., Lond., F.E.S.,
Assistant Naturalist in the Science and Art Museum, Dublin.

(PLATE XVII.)

THE dragonflies are insects specially appropriate for study from a distributional point of view. They are an isolated group, so distinct in structure and development from other insects which resemble them superficially, that most modern entomologists regard them as worthy to be ranked as a separate order (Odonata). Then they can be traced back to a somewhat remote geological period. Remains of insects referred without doubt to some of the existing sub-families have been found in the Upper Lias of South England, and are numerous in the (Oolitic) lithographic stone of Bavaria; while wings from the Devonian and Carboniferous formations are believed by Brongniart to have belonged to insects nearly related to dragonflies, to which he applies the name of Protodonata. In studying the distribution of the dragonflies, therefore, we have to deal with a group of animals which had become differentiated into their principal existing types at a period when the dominant vertebrates were the ichthyosaurs, plesiosaurs, and dinosaurs, and when neither the placental mammals nor the higher birds had yet been developed. It is of considerable interest to find how well the regions, into which the earth's surface has been divided to indicate the distribution of those modern groups, suit that of this ancient order of insects.

Students of the dragonflies from any standpoint owe a debt of

gratitude to Mr. W. F. Kirby for his invaluable catalogue[1] of the order. The present paper has been compiled chiefly from that catalogue, the nomenclature of which has been adopted in spite of some highly inconvenient revolutions, necessitated by the application of the law of priority. The most important of these is the restoration of the name *Agrion* to the genus which Leach called *Calopteryx*, a new name, *Cœnagrion*, being coined to replace *Agrion* as used by Leach and subsequent writers. The recognised division of the Odonata into six well-marked sub-families has been followed, and these are apportioned among three families—Libellulidæ, Æschnidæ, and Agrionidæ—as in the usual classification. Mr. Kirby's catalogue was published in 1890. All genera described since, so far as I have been able to ascertain them, have been inserted ; and in reckoning the number of species in each genus I have also tried to incorporate the latest results, so that the tables given below may be taken to represent our knowledge of the subject at the end of the present year (1896). Where the name in Mr. Kirby's catalogue differs from that in general use, the latter is added in parenthesis.

The regions and sub-regions adopted in the tables of distribution are, on the whole, those of Sclater and Wallace.[2] I have, however, reckoned the Mascarene division of the Ethiopian as a separate region, and it will be found that the dragonfly-fauna of Madagascar and the adjacent islands has no more affinity with that of Africa than with that of Oriental Asia. Also I have divided the Nearctic region as suggested by Dr. Hart Merriam,[3] adding the Canadian sub-region to the Palæarctic to form a Holarctic region, and calling the rest of extra-tropical North America, Sonoran. While the distribution of dragonflies affords considerable support to this revision of the classic zoological regions, it must be admitted that several Holarctic genera range over the Sonoran. As a rule, however, the Holarctic genera do not range southward nor the Sonoran northward beyond Merriam's Tran-

---

[1] "A Synonymic Catalogue of Neuroptera Odonata." London, 1890.

[2] "The Geographical Distribution of Animals." 2 vols. London, 1876.

[3] Proc. Biol. Soc. Washington, vol. vii., 1892, pp. 1–64. Also Natural Science, vol. v., 1894, p. 53.

sition Zone. Dragonflies are naturally apt to spread widely, and it is appropriate to consider a genus peculiar to a region when it only transgresses the frontiers for a short distance or, if a large genus, with but one or two species.

The Manchurian sub-region of the Holarctic has a large Oriental element in its dragonflies; indeed it is to some extent a transition zone between the two faunas. In dealing with the Malayan sub-regions I have regarded Celebes as Oriental; its dragonflies seem to show more Oriental than Australian affinities. There is, however, much similarity between the Oriental and Australian dragonflies, a number of characteristically Oriental forms range into Papua and even into Australia and Polynesia.

The distribution of the genera of each sub-family is shown in the following tables. The figure after each genus indicates the total number of known species, and the figures in the columns show the number of species found in each sub-region. By this means it is seen at a glance how widely each genus ranges, and in what districts it is most abundantly represented. At the end of the tabular view of the distribution of each sub-family I have pointed out what genera occur in or are peculiar to the various regions.

A short summary of the distribution of dragonflies, compiled from tables furnished by M. R. Martin, is to be found in Dr. Trouessart's excellent little book[1] on geographical distribution. It will be seen that the statements there made regarding the absence of certain sub-families from various districts require modification. The Agrionines (Calopteryginæ) are represented in Madagascar (though only by one species) as well as in Papua. Libellulines occur both in New Zealand and Polynesia, and Æschnines in Polynesia and Madagascar.

---

[1] "La Geographie Zoologique," (pp. 275–6.) Paris, 1890.

LIBELLULIDÆ.
Libellulinæ.

GENERA	NEOTROPICAL Chilian	NEOTROPICAL Brazilian	NEOTROPICAL Mexican	NEOTROPICAL Antillean	SONORAN	HOLARCTIC Canadian	HOLARCTIC Siberian	HOLARCTIC European	HOLARCTIC Mediterr.	HOLARCTIC Manchurian	ETHIOPIAN W. African	ETHIOPIAN S. African	ETHIOPIAN E. African	MASCARENE	ORIENTAL Hindostan	ORIENTAL Ceylon	ORIENTAL Ind.-Chin.	ORIENTAL Ind.-Mal.	AUSTRALIAN Aust.-Mal.	AUSTRALIAN Australian	AUSTRALIAN Polynesian	AUSTRALIAN N.Zealand
Tholymis (3),	—	—	—	1	—	—	—	—	—	—	1	—	1	—	1	1	1	1	1	—	—	—
Pantala (2),	—	1	1	2	2	—	—	—	1	1	1	1	1	—	1	1	1	1	—	—	—	—
Hydrobasileus (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	—	—	—
Camacinia (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1	1	—	—
Antidythemis (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Tramea (33),	—	8	2	5	5	—	—	—	—	—	3	—	—	3	—	—	2	3	—	—	3	—
Tauriphila (3),	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Miathyria (4),	—	2	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudothemis (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Rhyothemis (35),	—	—	—	—	—	—	—	—	—	1	—	—	—	3	1	2	2	9	5	5	3	—
Neurothemis (9),	—	—	—	—	—	—	—	—	—	3	—	—	—	—	2	2	2	6	3	3	—	—
Diastatops (4),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zenithoptera (2),	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Palpopleura (6),	—	2	—	—	—	—	—	—	2	—	3	2	1	—	1	—	1	—	—	—	—	—
Perithemis (11),	—	3	2	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudoleon (1),	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Celithemis (5),	—	—	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leucorhinia (13),	—	—	—	—	—	6	6	5	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Cœnotiata (1),	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zonothrasys (1),	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Platyplax (1),	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sympetrum (= Diplax) (46),	—	3	—	8	10	6	6	13	7	8	2	—	—	—	1	—	3	—	2	3	3	1
Thecadiplax (7),	—	—	2	—	2	—	—	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—
Trithemis (51),	1	—	1	—	—	—	—	—	4	—	4	5	5	4	6	1	5	6	—	—	—	—
Erythrodiplax (6),	2	12	2	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1	—	—	—	—
Brachythemis (1),	—	2	—	—	—	—	—	—	—	—	1	—	—	—	1	—	1	1	—	—	—	—
Crocothemis (6),	4	—	—	—	—	—	—	—	1	—	1	1	1	1	4	1	1	1	1	2	—	—

Macrodiplax (1),					1		2	2 1	2		2	2											
Urothemis (12),							1																
Æthriamanta (2),				1					1														
Onychothemis (2),											1												
Libellula (= Platetrum) (1),								1															
Dicranopyga (1),																							
Untamo (1),			1																				
Lyriothemis (9),				1																			
Amphithemis (2),			4	2				3				1	3										
Orthemis (3),																							
Olpogastra (1),																							
Leptetrum (= Libellula) (14),	2 3	4 1 6 2		1 1		2 2 1 1				5 3 4 5			1										
Plathemis (3),	2		1	1		1							3										
Belonia (10),						1							5										
Holotania (5),		1				1																	
Thermorthemis (4),		1																					
Nymphentria (2),																							
Hadrothemis (1),		1																					
Helothemis (1),		1																					
Protorthemis (2),		1 1	1			1							1										
Nesocia (3),																							
Apatelia (1),																							
Lathrecista (6),																							
Potamarcha (1),					1																		
Nesoxenia (6),		1			1																		
Agrionoptera (6),																	1						
Chalcostephia (1),																							
Raphismia (1),																							
Cordulions (1),			2 1																	3 1 9 2				
Anatya (1),																							
Tyriobapta (1),																							
Bradinopyga (1),																							
Hemistigma (3),																							
Thermochoria (1),																							
Uracis (3),																					4 1	1		
Misagria (2),															1								
Macrothemis (13),																							
Ephidatia (3),																							

LIBELLULIDÆ.

Libellulinæ.

GENERA.	NEOTROPICAL				SONORAN.	HOLARCTIC.					ETHIOPIAN.			MASCARENE.	ORIENTAL.				AUSTRALIAN.			
	Chilian.	Brazilian.	Mexican.	Antillean.		Canadian.	Siberian.	European.	Mediterr.	Manchurian.	W. African.	S. African.	E. African.		Hindostan.	Ceylon.	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian.	Polynesian.	N. Zealand.
Tholymis (3),	—	—	—	1	—	—	—	—	—	—	1	—	1	—	1	1	1	1	—	—	—	—
Pantala (2),	—	1	1	2	2	—	—	—	1	—	1	1	1	—	1	1	1	1	1	—	—	—
Hydrobasileus (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—
Camacinia (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—
Antidythemis (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tramea (33),	—	8	2	5	5	—	—	—	—	—	3	—	—	3	3	1	2	3	2	1	3	—
Tauriphila (3),	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Miathyria (4),	—	2	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudothemis (1),	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Rhyothemis (35),	—	1	—	—	—	—	—	—	2	3	2	—	—	3	1	2	1	9	5	5	3	—
Neurothemis (9),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	2	6	3	3	—	—
Diastatops (4),	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zenithoptera (2),	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Palpopleura (6),	—	—	—	—	—	—	—	—	—	—	3	2	1	1	—	1	—	—	—	—	—	—
Perithemis (11),	1	3	2	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudoleon (1),	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Celithemis (5),	—	—	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leucorhinia (13),	—	—	—	—	—	6	—	5	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Cematinia (1),	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zonothrasys (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Platyplax (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sympetrum (= Diplax) (16),	1	3	1	—	10	6	6	13	7	8	2	—	—	—	1	—	3	—	—	—	—	—
Thecadiplax (7),	—	—	—	—	—	—	—	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—
Trithemis (51),	—	—	—	—	—	—	—	—	4	—	4	5	5	4	6	1	5	6	2	3	3	1
Erythrodiplax (6),	2	12	2	8	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Brachythemis (3),	—	—	—	—	—	—	—	—	1	—	1	1	1	1	4	1	1	1	—	—	—	—
Crocothemis (6),	—	—	—	—	—	—	—	—	—	—	1	1	1	1	1	1	1	1	1	2	—	—
Microthemis (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—
Brachydiplax (8),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	4	1	1	—	—
Brachygonia (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—	—
Deielia (3),	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	1	1	—	—	—	—
Macrodiplax (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—
Urothemis (12),	—	—	—	—	—	—	—	—	2	—	2	2	2	1	2	—	5	1	—	—	—	—
Æthriamanta (2),	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	1	—	—	—	—
Onychothemis (2),	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	1	—	—	—	—	—
Libellula (= Platetrum) (1),	—	—	—	—	—	—	—	1	1	—	—	—	—	1	—	—	—	—	—	—	—	—
Dicranopyga (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Untamo (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Lyriothemis (9),	—	—	—	—	—	—	1	—	—	3	—	—	—	—	—	1	4	—	—	—	—	—
Amphithemis (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—
Orthemis (3),	—	3	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oipogastra (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Leptetrum (= Libellula) (14),	—	1	3	—	5	3	1	3	1	2	—	—	—	—	—	—	—	—	—	—	—	—
Plathemis (3),	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bolonia (10),	—	2	5	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Holotania (5),	—	—	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Thermorthemis (4),	—	—	—	—	—	—	—	—	—	2	1	—	1	—	—	—	—	—	—	—	—	—
Nymphentria (2),	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
Hadrothemis (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Helothemis (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Protorthemis (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
Nesocria (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—
Apatelia (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Lathrecista (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	4	2	1	1	—
Potamarcha (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	—	—	—	—
Nesoxenia (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—	—	—	—	—
Agrionoptera (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	2	1	—	1	—
Chalcostephia (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—
Raphismia (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Corduliops (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Anatya (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tyriobapta (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Bradinopyga (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Hemistigma (3),	—	—	—	—	—	—	—	—	—	2	—	—	—	1	—	—	—	—	—	—	—	—
Thermochoria (1),	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Uracis (3),	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Misagria (2),	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Macrothemis (13),	—	9	—	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ephidatia (3),	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Libellulinæ—*continued*.

N. Zealand.	Polynesian.	Australian.	Aust.-Mal.	Ind.-Mal.	Ind.-Chin.	Ceylon.	Hindostan.	MASCARENE.	E. African.	S. African.	W. African.	Manchurian.	Mediterr.	European.	Siberian.	Canadian.	SONORAN.	Antillean.	Mexican.	Brazilian.	Chilian.	GENERA.
																		1		1		Brechmorhoga (1),
																		2	2	2		Paltothemis (1),
																	4	1		1		Dythemis (10),
																				1		Scapanea (1),
											1											Rhodopygia (1),
											2											Porpax (1),
											1											Pseudomacromia (2),
				1	8	7	1	1	5	5	1	6	11	5	1		1	1		1		Idiomacromia (1),
				8		7	7	6			5							1		1		Cannacria (2),
	1	1	1														2			1		Neocysta (1),
		3	3		1	1			1		1		2				1		2	1		Zyxomma (5),
				2														2	2	3		Orthetrum (56),
				2														2	2	1	1		Lepthemis (4),
																		4	1	3		Oligoclada (1),
																				1		Mesothemis (3),
								3	1	2	1		2					1	1	1		Erythemis (4),
		1	1	3	1	1	1	1	1	1	1		1				1	1		1		Pachydiplax (1),
											2											Archiolops (1),
																						Cannaphila (2),
																						Micrathyria (7),
																						Cacergates (2),
																						Melanarptis (1),
																						Calothemis (3),
																						Orchithemis (2),
																						Diplacodes (7),
																						Diplacina (4),
																						Agrisoma (4)

Nannophlebia (1),	
Nannodiplax (2),	
Fylgia (2),	
Nannothemis (3),	
Nannophya (1),	
Dasythemis (1),	
Neodythemis (1),	
Hypothemis (1),	
Micromacromia (1),	
Allorhizucha (2),	
Zygonyx (2),	
Schizopyga (1),	

Libellulinæ—*continued*.

GENERA	NEOTROPICAL				SONORAN	HOLARCTIC					ETHIOPIAN			MASCARENE	ORIENTAL				AUSTRALIAN			
	Chilian	Brazilian	Mexican	Antillean		Canadian	Siberian	European	Mediterr.	Manchurian	W. African	S. African	E. African		Hindostan	Ceylon	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian	Polynesian	N.Zealand
Brechmorhoga (1)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Paltothemis (1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dythemis (10)	—	2	2	2	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Scapanea (1)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhodopygia (1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Porpax (1)	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Pseudomacromia (2)	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—
Idomacromia (1)	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Cannacria (2)	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neocysta (1)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zyxomma (5)	—	—	—	—	—	—	—	—	—	—	1	—	—	1	1	—	—	1	1	—	—	—
Orthetrum (56)	—	—	—	—	—	—	1	5	11	6	5	5	5	6	7	7	8	8	3	3	1	—
Lepthemis (4)	—	3	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oligoclada (1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mesothemis (3)	—	1	2	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Erythemis (4)	—	3	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pachydiplax (1)	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Archiclops (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—
Cannaphila (2)	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Micrathyria (7)	—	1	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cacergates (2)	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Melanarptis (1)	—	1	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—
Calothemis (3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
Orchithemis (2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—
Diplacodes (7)	—	1	1	1	1	—	—	—	1	—	1	2	1	3	1	1	—	2	1	—	—	—
Diplacina (4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—
Acisoma (4)	—	—	—	—	—	—	—	—	1	—	2	1	1	1	1	1	1	1	1	—	—	—
Neophlebia (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	1	—	—	—	—
Nephopeltia (1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nannodythemis (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Nannophlebia (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Nannodiplax (2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Fylgia (2)	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nannothemis (3)	—	1	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nannophya (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—
Dasythemis (1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neodythemis (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Hypothemis (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Micromacromia (1)	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Allorhizucha (2)	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—
Zygonyx (2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
Schizopyga (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—

Excluding *Celithemis,* *Holotania,* and *Pachydiplax,* three Sonoran genera which range south into Cuba or Mexico; the NEOTROPICAL REGION has forty-two genera of Libellulinæ, of which as many as twenty-seven to be found nowhere else. We may reckon, however, thirty peculiarly Neotropical genera, as three others— *Dythemis,* *Lepthemis,* and *Macrothemis*—only range north into Texas, Florida, or Lower California. The Chilian sub-region is very poor in this sub-family, which is represented there only by one characteristic genus (*Erythrodiplax*), and a few species of three wide-ranging genera. The Brazilian sub-region has thirteen of the peculiar genera confined to it, but of a large proportion of these, only one or two species each are as yet known. Six genera have been found in the Brazilian and West Indian sub-regions, but not in the Mexican, while two are apparently quite confined to the West Indian Islands. Studying the distribution of species, the nearer affinity of the Antillean dragonfly fauna to that of South, than to that of Central America, has been pointed out by Kolbe[1] and the present writer.[2] The distribution of the genera of Libellulinæ give the same result, for, excepting *Micrathyria* and *Cannaphila,* no genus absent or nearly so in the Brazilian sub-region is characteristic of both Central America and the West Indies.

There are three genera—*Perithemis, Mesothemis, and Nannothemis*—which are divided between the Sonoran and Neotropical Regions, ranging northwards to Merriam's transition zone on the southern borders of Canada. Including these three, but excluding *Dythemis, Lepthemis,* and *Macrothemis* mentioned above, the SONORAN REGION possesses fourteen genera of Libellulinæ, of which four— *Celithemis, Plathemis, Holotania,* and *Pachydiplax* are characteristic or peculiar. The remaining seven genera found in the Sonoran Region are all wide ranging; three of them—*Pantala, Trithemis,* and *Diplacodes*—are distinctly tropical, and should perhaps be regarded as incursors in the Sonoran.

The HOLARCTIC REGION is inhabited by eighteen genera of Libellulinæ, but eight of these must be regarded as incursors from the tropical regions Oriental and Ethiopian. Indeed, the southern Holarctic sub-regions show a very evident overlapping of the northern and tropical faunas. Five genera are peculiar to the Holarctic Region; two of these are confined to the Manchurian

[1] Archiv für Naturgeschichte, liv., 1 Band., 1888, pp. 153–176.
[2] Journal Inst. of Jamaica, vol. ii., 1896, pp. 259–263.

sub-region; and it is of interest to note that while one *Pseudo-themis* is closely allied to the tropical *Rhyothemis*, the other (*The-cadiplax*) is an offshoot of the northern *Sympetrum*. The other three peculiar Holarctic genera are *Libellula* (European and Mediterranean sub-regions), *Cœnotiata* (European), and *Leu-corhinia*, which ranges over the Canadian, European, and Man-churian sub-regions, some species presumably awaiting discovery in the Siberian. It is important to note that this genus in America ranges south only as far as the northern States.

Thirty-one genera of Libellulinæ are found in the Ethiopian Region; fourteen of these occur nowhere else, and three others only extend into the Mascarene Region, which is comparatively very rich, having nineteen genera—one more than the great Hol-arctic Region. Of these nineteen, six are peculiar. It will be noted that the distinction of the Ethiopian and Mascarene Regions is well warranted, fourteen peculiar genera characterising the one region and six the other, while only three are peculiar to the two combined. Of the fourteen peculiar Ethiopian genera, twelve are confined to the West African sub-region.

The Oriental Region is the home of forty-one genera, nearly the same number as inhabit the Neotropical Region; only twelve of these are peculiar, but four others might be reckoned with them, as they only range into the adjoining Austro-Malayan district. Two genera (*Æthriamanta* and *Onychothemis*) are Mascarene and Oriental only, the former occurring in Madagascar and India, the latter in Madagascar and the Philippines.

The Australian Region has twenty-eight Libelluline genera, but twelve of these are wide-ranging or Oriental genera which only enter the Austro-Malayan sub-region. Eight of the Aus-tralian genera are peculiar. Only a single species of the wide-ranging *Trithemis* reaches New Zealand, but the Polynesian sub-region has representatives of eight genera; one of these (*Hypo-themis*) is peculiar to the Fijis. The Libellulines of the Sandwich Islands mostly show affinity with North American forms. It is interesting to note that as many as eleven genera are Oriental and Australian only.

Turning now to the genera of wide range, we find that only eight are common to the tropical regions of both hemispheres. *Tholymis* is Oriental, Ethiopian and Neotropical (Antillean only). *Pantala* has a wider range, being found all over the three regions just mentioned, and extends into the southern Sonoran and

Holarctic, as well as to Papua. *Tramea* is Neotropical, Sonoran, Ethiopian, Mascarene, Oriental, and Australian; *Rhyothemis* has a somewhat similar range, but it extends into the southern Holarctic, while its presence in South America has only recently been made known by the discovery of a single species there. *Sympetrum* is characteristically a northern genus; most abundant in Holarctic and Sonoran regions, it is sparingly represented in the Neotropical, Ethiopian, and Oriental, but is absent from Madagascar and the Australian Region. *Trithemis* is the most widespread genus of the sub-family, occurring in all the Neotropical, Ethiopian, Oriental and Australian sub-regions, as well as in Madagascar; it has, however, but a single Sonoran species, and is only found in one Holarctic sub-region. *Leptetrum* is common to the Holarctic, Sonoran, and Neotropical Regions, while *Diplacodes* is Neotropical, Sonoran, Ethiopian, and Oriental, one species entering the southern Holarctic.

Among wide-ranging genera confined to the eastern hemisphere, we have *Palpopleura* which is Ethiopian, Mascarene, and Oriental. *Urothemis* has a similar but somewhat wider range, spreading north to the Mediterranean, and east to the Austro-Malayan sub-region. *Deielia* is Holarctic, Oriental, and Polynesian, having two species in China and Japan, and one in the Hawaian Islands. *Zyxomma* has characteristic species in West Africa, the Seychelles, India and Australia, Sumatra, and Papua. *Orthetrum* occurs in all Holarctic sub-regions except the Canadian, in all Australian sub-regions except New Zealand, and all over the Ethiopian, Mascarene, and Oriental Regions. It is a very variable genus with a large number of species exhibiting considerable diversity of structure, and appears therefore to be a dominant group in process of extension and development. *Acisoma* ranges all over the Ethiopian, Oriental, and Mascarene Regions, one species invading the southern Holarctic.

Fossil dragonflies referred to the Libellulinæ have been found in the Lower Purbeck of England, and the lithographic stone of Bavaria; these belong to the genera *Æschnidium* and *Libellulium.* There are other fossil Libellulines from various Secondary and Tertiary deposits referred to " *Libellula,*" but the generic name cannot stand for them in its modern, restricted sense. The Tertiary species outnumber the Secondary, and the comparatively large proportion of existing wide-ranging genera confirms the impression that the sub-family is still vigorous and developing.

Cordulinæ.

GENERA	Chilian	Brazilian	Mexican	Antillean	SONORAN	Canadian	Siberian	European	Mediterran.	Manchurian	W. African	S. African	E. African	MASCARENE	Hindostan	Ceylon	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian	Polynesian	N. Zealand
Neoplaya (1),											1											
Cordulephya (1),																				1		
Pentathemis (1),																				1		
Hemicordulia (10),														3						4	3	3
Somatochlora (36),					8	1	3	1		1							1					
Neurocordulia (4),					3	1																
Tetragoneuria (9),					7	1		1														
Epicordulia (2),					2			1														
Epitheca (1),						1	1	1	1													
Cordulia (2),						2	1	1	1													
Oxygastra (1),								1	1													
Syncordulia (2),												1		1								
Gomphomacromia (2),	1	1																				
Neocordulia (1),																						
Neocordulia (4),		4																				
Æschnosoma (3),	1	3																				
Epophthalmia (9),					2						2				1		1	3				
Macromia (14),					5				1	2	1		2		1	1	1	2		2		
Pseudogomphus (1),																						
Didymops (1),					1									1								
Phyllomacromia (4),											1	1										
Idionyx (2),																	1	1				
Synthemis (8),																				6	2	

A striking fact in the distribution of the Corduliinæ is their comparative scarcity in the NEOTROPICAL REGION. Only four genera, three of which are peculiar, out of the twenty-three included in the sub-family, occur in the region, and none of the species are found in Central America or in the West Indies. The SONORAN REGION has seven genera, of which two (*Epicordulia* and *Didymops*) are peculiar; and two others (*Neurocordulia* and *Tetragoneuria*), though they evidently range into the Canadian sub-region, may be fairly reckoned as Sonoran, the bulk of their species being southern. Excluding the Sonoran stragglers just mentioned, the HOLARCTIC REGION is seen to be entitled to six genera, of which three are peculiar. *Oxygastra* is European and Mediterranean, and *Epitheca* European and Siberian, while *Cordulia* is European, Mediterranean, Siberian, and Canadian. The ETHIOPIAN REGION, like the Neotropical, is poor in Corduliinæ, possessing only four genera. Two of these, *Neophya* and *Pseudogomphus*, are peculiar; a third, *Phyllomacromia*, has three species in Africa, and one in Madagascar. The MASCARENE REGION has two other genera, of which one, *Nesocordulia*, is confined to Madagascar, while the other (*Hemicordulia*) is Mascarene, Oriental, and Australian. Five genera are found in the ORIENTAL REGION, but only one, *Idionyx*, is peculiar. It is noteworthy that the Indo-Malayan sub-region has all five of the genera, the Indo-Chinese three, and Hindustan only two. The AUSTRALIAN REGION has six genera, four of which (*Cordulephya*, *Pentathemis*, *Syncordulia*, and *Synthemis*) are confined to it; it is noteworthy that only the last of these four ranges beyond the Australian continent.

Nineteen of the twenty-three genera of Corduliinæ are thus seen to be practically confined to one or other of the various regions, a very high degree of faunistic specialisation. The remaining four genera exhibit distributions of considerable interest. *Hemicordulia* has most of its species in Australia and Polynesia, one species in Celebes (which we reckon as belonging to the Indo-Malayan sub-region of the Oriental), one in the Khasia Hills, one in Madagascar, and one in Mauritius. Such discontinuous range, and particularly the almost total absence of the genus from the Asiatic continent suggests an ancient and decadent group.

The distribution of *Somatochlora* is very suggestive. The

Canadian sub-region of the Holarctic is the headquarters of the genus, possessing ten of the thirty-six species. Though five species invade the Sonoran Region they do not range far to the south, none reaching Texas or Florida, and the genus is evidently to be reckoned as belonging to the Holarctic fauna. Twelve species are found in the old world sub-regions of the Holarctic; of these none enter the Mediterranean district. Three occur in Siberia, one in the Amur, and three in Japan. Then coming south from Japan into the tropics, a single species is known from the Philippines, while at the antipodes, Australia has two species, and New Zealand three. In the Neotropical Region two species are found; one in Chili and one in Brazil (Para). The gaps in the range of the genus are very remarkable, and the whole distribution strikingly recalls that of the northern plants which extend to Chili and New Zealand, so familiar to students of biological geography through the classical works of Hooker and Wallace.[1]

Epophthalmia is divided between the Sonoran and Oriental Regions, and the Manchurian sub-region of the Holarctic. It seems likely that immigration between the American and Asiatic continents took place at a former warm period by a land-connection to the north of the Pacific, as must have been the case with many other groups of animals.

Macromia also has the bulk of its species in the Sonoran and Oriental Regions, but it extends to Ethiopian Africa, and has one species recorded from Southern France, while no species is known from Japan.

The Corduliinæ are the only sub-family of dragonflies which cannot be traced back to the Secondary Period. Only two fossil species are known—one Eocene and one Oligocene, both referred to the genus *Cordulia*. The Corduliinæ are closely allied to the Libellulinæ, from which they are not marked off by very clear structural characters, and their distribution, with so many genera peculiar to various regions, in conjunction with their comparatively recent geological age and present scarcity, suggests that they may have arisen from Libelluline ancestors independently in different parts of the world, and not attained any great success in the struggle for life.

---

[1] A. R. Wallace: "Island Life." 2nd edition. London, 1892 (p. 509, &c.).

ÆSCHNIDÆ.
Gomphinæ.

GENERA.	NEOTROPICAL.				SONORAN.	HOLARCTIC.					ETHIOPIAN.			MASCARENE.	ORIENTAL.				AUSTRALIAN.			
	Chilian.	Brazilian.	Mexican.	Antillean.		Canadian.	Siberian.	European.	Mediterr.	Manchurian.	W. African	S. African.	E. African.		Hindostan.	Ceylon.	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian.	Polynesian.	N. Zealand.
Gomphina.																						
Heterogomphus (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—
Crenigomphus (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Lindenia (=Onychogomphus) (35)	—	—	—	—	—	—	—	1	9	1	2	2	4	5	5	—	7	3	—	—	—	—
Herpetogomphus (10),	—	—	6	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Diastatomma (=Ophiogomphus) (9),	—	—	—	—	3	3	1	1	1	1	1	—	—	—	—	—	—	—	—	—	—	—
Ceratogomphus (2),	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
Phyllogomphus (1),	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Microgomphus (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Macrogomphus (9),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—
Octogomphus (1),	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dromogomphus (3),	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Æshna (=Gomphus) (54),	—	—	—	—	17	15	4	4	3	5	—	—	—	—	2	—	1	2	—	—	—	—
Anisogomphus (6),	—	—	—	—	—	—	1	—	—	—	—	—	—	—	2	—	2	—	—	—	—	—
Cyclogomphus (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	2	—	—	—	—	—
Anomogomphus (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Platygomphus (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Leptogomphus (4),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neurogomphus (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Podogomphus (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Austrogomphus (4),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—
Hemigomphus (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—
Neogomphus (3),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cyanogomphus (2),	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epigomphus (3),	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Diaphlebia (2),																				2	
Zonophora (3),																				3	
Hagenius (3),						1														1	
Davidius (4),																					
Sieboldius (2),					2	4				2 1												
Longchampia (2),		1			2 3			1		1		2 2										
Gomphidia (4),																					
Ictinus (15),					5			1 1													
Isomma (1),				1																	
Vanderia (= Lindenia) (i),				2																	
Cacus (1),			2	1																	
Corduligasterina.																					
Chlorogomphus (2),	1 4 2	3					1	1	1												
Orogomphus (3),		1				4															
Allogaster (1),					2																
Zoræna (1),					1																
Anotogaster (3),			1	2					1												
Thecagaster (2),	1				3 2			2													
Corduligaster (13),																					
Tæniogaster (2),																					
Petalia (1),	2 3 1			1																	
Phyllopetalia (4),				1 4 1	1																
Hypopetalia (1),																					
Petalura (1),																					
Uropetala (1),																					
Tachopteryx (3),																					
Phenes (1),																					

ÆSCHNIDÆ.

Gomphinæ.

GENERA.	Chilian.	Brazilian.	Mexican.	Antillean.	SONORAN.	Canadian.	Siberian.	European.	McJlbern.	Manchurian.	W. African.	S. African.	E. African.	MASCARENE.	Hindostan.	Ceylon.	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian.	Polynesian.	N. Zealand.
Gomphina.																						
Heterogomphus (3)																	3					
Crenigomphus (1)																						
Lindenia (=Onychogomphus) (35)								1	9	1	2	2	4	5	5		7	3				
Herpetogomphus (10)			6		4																	
Diastatomma (=Ophiogomphus) (9)					3	3		1	1	1												
Ceratogomphus (2)											1	1										
Phyllogomphus (1)											1											
Microgomphus (1)																		1				
Macrogomphus (9)							1								1		1					
Octogomphus (1)					1																	
Dromogomphus (3)					3										1		1					
Æshna (= Gomphus) (54)					17	15	4	4	3	5		1	2		1	1	1					
Anisogomphus (6)							1			1		1			2		1					
Cyclogomphus (6)															5		1					
Anormogomphus (1)															1							
Platygomphus (3)															1							
Leptogomphus (4)																						
Neurogomphus (1)											1											
Podogomphus (1)											1											
Austrogomphus (4)																				5		
Hemigomphus (6)		1																				
Neogomphus (3)		1																				
Cyanogomphus (2)	2	1																				
Epigomphus (3)				1																		
Cyclophylla (10)		1	7	2	1																	
Aphylla (7)			6																			
Diaphlebia (2)			2																			
Zonophora (3)			3																			
Hagenius (3)			1			1				1							1					
Davidius (4)										4												
Sieboldius (2)										2												
Longchampia (2)											2											
Gomphidia (4)																	2	2				
Ictinus (15)										3	1	2	1		5		3	4		1		
Isomma (1)														1								
Vanderia (= Lindenia) (1)										1												
Cacus (1)		1																				
Cordulegasterina.																						
Chlorogomphus (2)															1		1	2				
Orogomphus (3)															1		1	1				
Allogaster (1)															1							
Zorœna (1)							1															
Anotogaster (3)										1							2					
Thecagaster (2)																	2					
Cordulegaster (13)					3	2	1	2	4	1												
Tæniogaster (2)					2																	
Petalia (1)	1																					
Phyllopetalia (4)	4																					
Hypopetalia (1)	1																					
Petalura (1)																				1		
Uropetala (1)																						1
Tachopteryx (3)					2	1				1												
Phenes (1)	1																					

Of the fifty-five genera of Gomphinæ, eighteen are found in the NEOTROPICAL REGION. Sixteen of these may be reckoned as peculiarly Neotropical, including two (*Progomphus* and *Gomphoides*) which have each a species in the Sonoran. Except for four peculiar Chilian genera, the Cordulegasterine section is absent from the Neotropical Region. *Herpetogomphus* is divided between the Mexican sub-region and the Sonoran; though it has but four species in the United States to six in Mexico, its affinities suggest that it is a Sonoran genus invading the tropics. The SONORAN REGION possesses eight other Gomphine genera (not reckoning the two Neotropical stragglers mentioned above), but only three (*Octogomphus, Dromogomphus,* and *Tæniogaster*) can be claimed as peculiar.

Excluding *Macrogomphus*, an Oriental genus with one species in Thibet, and *Ictinus*, an Oriental and Ethiopian genus with three species in China, the HOLARCTIC REGION has twelve genera of Gomphinæ, of which four only (*Davidius, Sieboldius, Vanderia,* and *Zoræna*) are peculiar. These are, all four, small genera, and it is noteworthy that the first and second are confined to the Manchurian, the third to the Mediterranean, and the fourth to the Canadian sub-region.

The ETHIOPIAN REGION has ten genera, of which six are peculiar, but nearly all of these have only one species each. The MASCARENE REGION has five species of the wide-ranging genus *Lindenia* (= *Onychogomphus*), and the peculiar genus *Isomma* with one species. In the ORIENTAL REGION are found eighteen genera, just the same number as the Neotropical possesses; thirteen of these may be reckoned as peculiar to the region. The AUSTRALIAN REGION is very poor in Gomphines. The Austro-Malayan and Polynesian sub-regions are apparently devoid of these dragonflies; and Australia and New Zealand have but five genera. Three of these are peculiar, and it is noteworthy that the Australian *Petalura* and the New Zealand *Uropetala* are allied to Neotropical genera confined to the Chilian sub-region, while the genus *Hemigomphus* has five Australian and one Brazilian species.

The wide-ranging gomphine genera show many points of interest in their distribution. *Lindenia* (= *Onychogomphus*) is dominant over the Oriental and Ethiopian Regions, and spreads

into the southern Holarctic sub-regions, having nine Mediterranean species. *Anisogomphus*, with far fewer species, has a much more discontinuous range in the tropics, and invades only the south-eastern Holarctic districts. *Diastatomma* and *Cordulegaster* may perhaps be reckoned as characteristically Holarctic genera; but in both cases the Canadian sub-region is hardly richer in species than the Sonoran. Both genera occur in most of the European and Asiatic sub-regions of the Holarctic. The large genus *Æschna* or *Gomphus* shows a somewhat similar range, but the great majority of its species are about equally divided between the Canadian sub-region and the Sonoran. A fair number of species occur in the European and Asiatic districts of the Holarctic, stragglers ranging as far south as Abyssinia in the Ethiopian, and Assam and Madras in the Oriental Region. The range of *Hagenius* is very remarkable; one species is Neotropical and Sonoran, one Japanese, and one North Indian; but it should be mentioned that the two latter are doubtfully referable to the genus. *Ictinus* is widely spread over the Oriental and Ethiopian Regions, and has five species in Madagascar; as noted above, it invades the Manchurian sub-region of the Holarctic, and there is also one species in Australia. *Anotogaster*, with two species in northern India and one in Japan, is hardly more Oriental than Holarctic.

Striking facts in the distribution of Gomphine dragonflies are their absence from the Austro-Malayan and Polynesian sub-regions, and their scarcity in Madagascar and Ceylon. The affinity of the southern Neotropical with the Australian and New Zealand gomphines has already been mentioned. The genera in question all belong to the division Cordulegasterina, which is absent not only from Austro-Malayan, but also from the whole Neotropical Region except Chili. Such isolation of animal groups at the extremities of the southern regions has often been invoked to support the theory of an ancient Antarctic continent. In the present instance, however, we fortunately have some evidence from fossils by which to check our speculations. The Gomphinae are believed to be one of the most primitive of the odonate sub-families, and remains of dragonflies referable to them have been discovered in rocks as old as the Lias. Quite a number of

species have been described from the Solenhofen lithographic stone, and among these are four referable to the genus *Uropetala*, now confined to New Zealand. It would seem, therefore, that we have here striking proof of the truth of Wallace's[1] explanation of the discontinuous range of animals in far southern lands : that they are the last survivors of groups that at one time inhabited the great northern continents. Were fossil evidence available in other cases, such, for instance, as that of the earthworms common to New Zealand and Patagonia, it would possibly be found equally needless to imagine a sunken continent in order to explain the facts.

[1] *Op. cit.*, pp. 525, 526.

Æschninæ.

GENERA.	NEOTROPICAL				SONORAN	HOLARCTIC					ETHIOPIAN			MASCARENE	ORIENTAL				AUSTRALIAN			
	Chilian.	Brazilian.	Mexican.	Antillean.		Canadian.	Siberian.	European.	Mediterr.	Manchurian.	W.African	S.African.	E.African.		Hindostan.	Ceylon.	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian.	Polynesian.	N.Zealand.
Anax (24),	1	2	3	1	3	2	2	2	—	2	2	3	—	3	2	—	2	2	1	—	2	—
Hemianax (2),	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	—	—
Oligoæschna (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	1	—
Anaciæschna (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	1	—	—
Æschna (44),	5	10	5	—	7	7	5	6	2	3	—	—	2	—	—	—	—	—	—	—	—	—
Epiæschna (2),	—	1	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Brachytron (1),	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Acanthæschna (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
Austroæschna (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Gomphæschna (2),	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Allopetalia (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Basiæschna (1),	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fonscolombia (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Amphiæschna (3),	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—
Caliæschna (1),	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Cephalæschna (2),	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	2	1	1	—	—
Telephlebia (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Æschnophlebia (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—
Tetracanthagyna (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—
Gynacantha (=Triacanthagyna) (3)	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
Acanthagyna (=Gynacantha) (25)	—	9	1	2	—	—	—	—	—	—	4	—	—	2	—	—	1	7	3	—	—	—
Heliæschna (1),	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Neuræschna (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Staurophlebia (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

The NEOTROPICAL REGION possesses eight of the twenty-four genera of this sub-family; only three of these are peculiar, but one other enters no other region save the Sonoran. In the SONORAN REGION four genera occur (neglecting Holarctic incursors), one only of which is peculiar. The HOLARCTIC REGION has eight Æschnine genera. Three only are confined to the region, but two others (_Basiæschna_ and _Fonscolombia_), which enter the northern Sonoran, may be reckoned with these. The ETHIOPIAN REGION possesses but four genera, one of which is peculiar. In the MASCARENE REGION the sub-family is represented by three species of the almost cosmopolitan _Anax_, and two of the wide-spread _Acanthagyna_. In the ORIENTAL REGION, eight genera are found. Three of these (_Oligoæschna_, _Cephalæschna_, and _Tetracanthagyna_) are peculiar, and one other (_Amphiæschna_) which transgresses into the Austro-Malayan sub-region may be reckoned with them. Nine genera (excluding this just mentioned) inhabit the AUSTRALIAN REGION; only three (all Australian) are confined to it. There appear to be no Æschnine dragonflies in New Zealand.

Of the wide-ranging genera, _Anax_ is nearly cosmopolitan, but appears to be absent from Australia and New Zealand. _Hemianax_ has a very curious range—one South European, and one Australian species. _Æschna_ is spread over the whole of the Neotropical and Holarctic Regions, but is almost unknown in the tropics of the eastern hemisphere; there is one (doubtful) species in India, one in Australia, and two in the mountains of East Africa. _Gynacantha_ has an interesting discontinuous range in the tropics, occurring in the Neotropical and Austro-Malayan Regions, while _Acanthagyna_ is more widely spread, being found in the Neotropical Region (where it is almost confined to the Brazilian and West Indian sub-regions) in West Africa, and in the Indo-Malayan district of the Oriental Region, some of the species extending thence into Papua. A surprising fact is that, with such a range, the genus has not been found in Madagascar, but Mauritius and the Seychelles have a species each.

Fossil Æschninæ appear to be less plentiful than fossil Gomphinæ. A single _Anax_ is recorded from the Oligocene of Radoboj, Croatia; and there are several extinct dragonflies referred to _Æschna_, the oldest of which is from the Lias. A species has been found in Cretaceous rocks in Queensland. This fact seems to indicate that the scattered range of the few species of the genus now found in the old-world tropics is due to its almost total extinction over those regions, though in Europe and America it appears to be fully holding its own in spite of its comparatively high antiquity.

AGRIONIDÆ.

Agrioninæ (Calopteryginæ, Auct.).

GENERA.	AUSTRALIAN				ORIENTAL				MASCARENE	ETHIOPIAN			HOLARCTIC					SONORAN	NEOTROPICAL			
	N.Zealand	Polynesian	Australian	Aust.-Mal.	Ind.-Mal.	Ind.-Chin.	Ceylon	Hindostan	Mascarene	E.African	S.African	W.African	Manchurian	Mediterr.	European	Siberian	Canadian	Sonoran	Antillean	Mexican	Brazilian	Chilian
Agrion (= Calopteryx) (18),	—	—	—	—	—	—	—	2	—	—	—	—	5	5	2	1	4	4	—	—	—	—
Matrona (3),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Umma (2),	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
Sapho (5),	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—	—	—
Archineura (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Mnais (4),	—	—	—	—	—	1	—	1	—	—	—	—	4	—	—	—	—	—	—	—	—	—
Psolodesmus (1),	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Echo (3),	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Phaon (1),	—	—	—	—	—	—	—	—	1	1	1	1	—	—	—	—	—	—	—	—	—	—
Neurobasis (3),	—	—	—	—	1	1	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vestalis (7),	—	—	—	—	5	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lais (14),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	14	—
Hetærina (42),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	2	12	26	—
Caliphæa (2),	—	—	—	—	—	1	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Bayadera (2),	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epallage (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
Anisopleura (3),	—	—	—	—	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudophæa (= Euphæa) (20),	—	—	—	—	10	7	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dysphæa (4),	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heliocharis (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—
Dicterias (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
Philoganga (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Amphipteryx (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Devadatta (1),	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Diphlebia (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Libellago (11),	—	—	—	—	1	—	—	—	—	1	1	8	—	—	—	—	—	—	—	—	—	—
Rhinocypha (35),	—	—	—	3	19	9	1	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Micromerus (15),	—	—	—	—	8	4	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chalcopteryx (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
Thore (18),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18	—
Euthore (6),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	—
Cora (13),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13	—
Palæophlebia (1),	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—

It will be seen that of the thirty-three genera included in this sub-family, nine are peculiar to the NEOTROPICAL REGION, and all of these appear to be confined to the Brazilian sub-region. The Chilian sub-region seems, like Australia, Polynesia, and New Zealand, to be entirely without Agrionines. The genus *Hetœrina* ranges through the Mexican sub-region into the Sonoran, and as far as Merriam's Transition Zone, and its range is over-lapped by that of the Holarctic genus *Agrion*, which comes south as far as Florida and Texas. Hence, so far as this sub-family is concerned, the SONORAN REGION, without characteristic genera of its own, is merely neutral ground between the Neotropical and the Holarctic; there is no more reason for annexing it to one than to the other.

The ETHIOPIAN REGION is comparatively poor in this sub-family. Of its four characteristic genera, two (*Umma* and *Sapho*) are peculiar to West Africa, and one (*Phaon*) ranges into Mada-gascar; the fourth (*Libellago*) is specially noteworthy as the only instance in the sub-family of discontinuous range; it has ten African species, and one in the Philippines.

The ORIENTAL is by far the richest region in Agrionines. Thirteen genera may be reckoned as peculiar, including the large and important *Rhinocypha*, which just transgresses the limits, having two species in Thibet, and three in Papua. Two other genera (*Matrona* and *Caliphaea*) are common to the northern Oriental and southern Holarctic (Manchurian). In the HOL-ARCTIC REGION we have four peculiar genera—*Epallage* in the Mediterranean sub-region; *Archineura*, *Mnais*, and *Palœophlebia* in the Manchurian, *Archineura* being confined to China, and the two last-named to Japan. Then there is the typical genus *Agrion* or *Calopteryx* spread all over the Holarctic and Sonoran Regions.

The distribution of the genera of this sub-family indicates a high degree of specialisation in the fauna of the different regions. The most notable fact is the almost entire absence of the sub-family from the Australian Region, only two Philippine species of the Oriental genus *Rhinocypha* ranging into Papua. In Mada-gascar the group is represented only by one widely-ranging Ethiopian species (*Phaon iridipennis*, Burm.). And in the West

Indies we find but one or two species of the widespread American genus *Hetærina*. The Agrioninæ are considered to be among the most primitive of dragonflies, and all the fossil insects referable to the sub-family come from the Solenhofen lithographic stone, and thus carry us back to the Jurassic period. It is, therefore, exceedingly strange that they should be unrepresented at the present day in the Australian Region, Madagascar, and the West Indies, except by species which are evidently comparatively recent immigrants from the neighbouring great continents. For it is well known that these countries are specially characterised as the sanctuaries of primitive forms of life. Yet it seems probable that the Agrionine dragonflies, for some reason, have only lately extended their range into these districts.

The genera peculiar to the Neotropical Region and their allies in the Oriental and Ethiopian appear to be the descendants of a primitive stock once widespread, for there are three Solenhofen species referred to *Pseudophœa*. Then a newer stock seems to be represented by the genera at the head of the table—*Agrion* and its allies. These are mostly Holarctic and Oriental, and it is remarkable how many genera are represented at the confines of the two regions, suggesting that from the Manchurian district the insects spread westward to Europe and Africa, and eastward into North America. The last genus in the table, *Palæophlebia*, confined to Japan, is of special interest as the most primitive of living dragonflies, combining the body of a Gomphine with the wings of an Agrionine.[1]

---

[1] D. Sharp : The Cambridge Natural History, vol. v. (p. 427). London: 1895.

Cœnagrioninæ.

GENERA.	AUSTRALIAN				ORIENTAL				MASCARENE.	ETHIOPIAN			HOLARCTIC					SONORAN.	NEOTROPICAL			
	N.Zealand.	Polynesian.	Australian.	Aust.-Mal.	Ind.-Mal.	Ind.-Chin.	Ceylon.	Hindostan.		E.African.	S.African.	W.African.	Manchurian.	Mediterr.	European.	Siberian.	Canadian.		Antillean.	Mexican.	Brazilian.	Chilian.
Pseudostigmatina.																						
Megaloprepus (1),																				1	1	
Microstigma (5),																					5	
Anomisma (1),																					1	
Mecistogaster (11),																			1	2	10	
Pseudostigma (2),																				2	1	
Normostigmatina.																						
Paraphlebia (2),																				2		
Philogenia (4),																					4	
Megapodagrion (10),																					10	
Mesopodagrion (1),																1						
Nesolestes (1),									1													
Mesagrion (1),																					1	
Heteropodagrion (1),																					1	
Heteragrion (17),																					17	
Perilestes (2),																					2	
Neurolestes (1),												1										
Chlorolestes (5),											5											
Allolestes (2),									2													
Podopteryx (1),				1																		
Argiolestes (9),			2			1																
Podolestes (2),					2																	
Synlestes (1),			1																			
Amphilestes (5),				5																		
Nesocnemis (1),									1													

Genus																			
Copera (9),																			
Platycnemis (11),					5	1		2	1				2	2					
Calicnemis (5),						5		1		1	2	1							
Metacnemis (3),																			
Allocnemis (3),																			
Mesocnemis (1),																			
Chlorocnemis (4),																			
Proneura (1),									1										
Palaemnema (6),		2	5																
Platysticta (14),					2	1	7	3				2	2				4	1	2
Protosticta (2),					10	1	5												
Disparoneura (26),		7			6													6	27
Caconeura (13),																			
Nososticta (1),																			
Isosticta (1),																			
Peristicta (1),																			
Idioneura (1),																			
Caenoneura (8),																			
Microneura (1),																			
Protoneura (10),																			
Hyponeura (2),															1				
Argia (49),					1			4	1	1	1	1	2	6	2	1	1	1	9
Onychargia (3),															1	8	1		
Ceratura (1),					2	2		1	1	1	1	3	1	1	8	11	7	3	1
Anomalagrion (1),												1	1		1	1		2	3
Micronympha (=Ischnura) (29),	4	4	1	1	1	2	4	1	1	1	2	6	2	1	1	11	7	1	8
Amphiagrion (4),															7	2			10
Oxyagrion (10),												1	1	1			1	1	
Acanthagrion (12),				1			1			1	1	1			2	2	3	1	8
Xiphiagrion (1),	5											10	12	6			1		10
Enallagma (41),	10								2			2	2	1		2	2		
Nehalennia (8),					2			1	1	1	1	4		1	1	1			
Nesobasis (5),															1	1			1
Coenagrion (= Agrion) (45),						2				1	1	2	2	2					
Pyrrhosoma (3),																			
Erythromma (7),																			
Neuragrion (1),																1			

Cœnagrioninæ.

GENERA.	NEOTROPICAL.				SONORAN.	HOLARCTIC.					ETHIOPIAN.			MASCARENE.	ORIENTAL.				AUSTRALIAN.			
	Chilian.	Brazilian.	Mexican.	Antillan.		Canadian.	Siberian.	European.	Mediter.	Manchurian.	W.African.	S.African.	E.African.		Hindostan.	Ceylon.	Ind.-Chin.	Ind.-Mal.	Aust.-Mal.	Australian.	Polynesian.	N.Zealand.
Pseudostigmatina.																						
Megaloprepus (1),	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Microstigma (5),	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Anomisma (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mecistogaster (11),	—	10	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudostigma (2),	—	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Normostigmatina.																						
Paraphlebia (2),	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Philogenia (4),	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Megapodagrion (10),	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mesopodagrion (1),	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nesolestes (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Mesagrion (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heteropodagrion (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heteragrion (17),	—	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Perilestes (2),	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neurolestes (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Chlorolestes (5),	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—	—	—
Allolestes (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
Podopteryx (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—
Argiolestes (9),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	5	2	—	—
Podolestes (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—
Synlestes (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Amphilestes (5),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—
Nesocnemis (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Priononemis (= Hyponemis) (8),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	—	—	—	—
Tatocnemis (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
Leptonemis (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	—	—	—	—
Caliocha (9),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	1	5	—	—	—	—
Copera (9),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	1	5	—	—	—	—
Platycnemis (11),	—	—	—	—	—	—	—	2	9	1	—	—	—	—	1	—	—	—	—	—	—	—
Calicnemis (5),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	5	—	—	—	—	—
Metacnemis (3),	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—
Allocnemis (3),	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—
Mesocnemis (1),	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Chlorocnemis (4),	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—
Proneura (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Palæmnema (6),	—	2	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Platysticta (14),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	—	5	2	—	—	—
Protosticta (2),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—
Disparoneura (26),	—	—	—	—	—	—	—	—	—	—	3	2	2	—	3	5	1	10	—	—	—	—
Caconeura (13),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	7	—	—	—	—
Nososticta (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Isosticta (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Peristicta (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Idioneura (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cœnoneura (8),	—	6	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Microneura (1),	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Protoneura (10),	—	9	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hyponeura (2),	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Argia (49),	—	27	8	—	11	—	1	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—
Onychargia (3),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	2	—	—
Ceratura (1),	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Anomalagrion (1),	—	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Micronympha (= Ischnura) (29),	—	3	—	—	7	1	2	6	2	—	1	1	1	1	4	—	2	2	—	4	4	—
Amphiagrion (4),	—	—	2	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oxyagrion (10),	2	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Acanthagrion (12),	2	10	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Xiphiagrion (1),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
Enallagma (41),	—	1	3	7	11	8	1	1	1	3	1	1	2	—	1	—	—	1	—	—	—	—
Nehalennia (8),	—	1	2	—	2	1	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Nesobasis (5),	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—
Cœnagrion (= Agrion) (45),	—	3	—	—	1	2	6	12	10	4	1	1	1	2	—	—	—	—	—	—	—	—
Pyrrhosoma (3),	—	—	—	—	—	1	—	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Erythromma (7),	2	—	—	—	1	—	1	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—
Neuragrion (1),	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Coenagrioninae—*continued.*

GENERA	AUSTRALIAN				ORIENTAL				MASCARENE	ETHIOPIAN			HOLARCTIC					SONORAN	NEOTROPICAL			
	N.Zealand	Polynesian	Australian	Aust.-Mal.	Ind.-Mal.	Ind.-Chin.	Ceylon	Hindostan		E. African	S. African	W. African	Manchurian	Mediterr.	European	Siberian	Canadian		Antillean	Mexican	Brazilian	Chilian
Pseudagrion (28),			2	4	5	1		2		2	1	8	1	1								
Aciagrion (1),					1	1																
Xanthagrion (4),	3		1																			
Ceriagrion (3),						1	1	1	1	1	1	1	1									
Brachybasis (1),												1										
Argiagrion (1),																						
Anisagrion (2),																				2		
Telebasis (=Erythagrion) (9),																			3	1	6	
Telagrion (4),																					4	
Leptagrion (12),																					12	
Megalagrion (2),		2																				
Leptobasis (6),																			1		5	
Archibasis (= Stenobasis) (4),			1	1	1				1													
Teinobasis (= Telebasis) (13),		1	1	5	8	1	1															
Amphicnemis (4),			1		4																	
Pericnemis (2),		1			1																	
Argiocnemis (6),					4	1		2	1													
Agriocnemis (14),			6		5	1	1	1	2	2		1										
Hemiphlebia (1),																						
Megalestes (1),																						
Orolestes (1),																						
Archilestes (1),																		1	2	1	1	
Ortholestes (2),																			2			
Lestes (62),	1				3	4	5	3		1	4	1	1	4	5		2	12		3	8	1
Sympycna (3),														2	2							
Platylestes (1),				1	1	1	1	1														

The Neotropical Region has forty genera of Cœnagrininæ; and thirty, a large proportion, are peculiar—these including the whole of that remarkable group the Pseudostigmatina which comprises the largest (though far from the most robust) of living dragonflies. Fourteen of the peculiar genera are confined to the Brazilian sub-region. The Chilian sub-region has representatives of four genera, two of which (*Oxyagrion* and *Acanthagrion*) are Neotropical, one (*Erythromma*) northern, and one (*Lestes*) cosmopolitan. Three genera (*Amphiagrion*, *Anomalagrion*, and *Archilestes*) are Neotropical and Sonoran.

As with the last sub-family, the Sonoran Region is destitute of characteristic forms. Only ten genera, all more or less widely-ranging, are represented there.

Fourteen genera of the sub-family are found in the Holarctic Region, but two of these (*Copera* and *Ceriagrion*) are Oriental incursors, only occurring in China and Japan. Only one genus (*Mesopodagrion* from Eastern Tibet) can be considered peculiar. But *Platycnemis*, with ten Holarctic species, has only one elsewhere—in Mauritius; while *Cœnagrion* and *Erythromma* have the majority of their species confined to the Holarctic Region. *Pyrrhosoma* has two European and one Californian species.

Sixteen genera inhabit the Ethiopian Region. Seven of them are found nowhere else, while another (*Brachybasis*) is confined to Africa and Madagascar. Four of the peculiar Ethiopian genera have only been recorded from West Africa.

The Mascarene Region is comparatively rich in dragonflies of the sub-family, possessing thirteen genera, of which five are peculiar. Except *Brachybasis*, mentioned above, as confined to this region and the Ethiopian, the non-peculiar Mascarene genera have all a wide or discontinuous range.

Twenty-seven genera of Cœnagrioninæ are found in the Oriental Region, thirteen of which can be reckoned as peculiar, including *Ceriagrion*, which transgresses the frontiers into China and Japan, and *Platysticta* with two, and *Archibasis* with one Papuan species. Two genera (*Caconeura* and *Onychargia*) are Oriental and Australian only. The Australian Region is almost as rich as the Oriental in this sub-family, having twenty-three genera, ten of which are not found elsewhere. New Zealand has

one species of the cosmopolitan *Lestes*, and three species of the characteristic *Xanthagrion*, which is also found in Australia.

Among the genera common to both hemispheres, *Argia* has the vast majority of its species Neotropical and Sonoran, but there is one species in South Africa, one in the Kurile Islands, off the east coast of Siberia, and one in the Moluccas. We may here have a genus which, richly represented in tropical America, is on the verge of extinction elsewhere. *Micronympha* and *Lestes* are almost cosmopolitan. *Enallagma* and *Cœnagrion* are widespread. Both are characteristically northern genera, but while the former is predominantly American, and has an Oriental, but no Australian, species, the latter is markedly European, seems unknown in the Oriental region, but has ten species in the Sandwich Islands. *Nehalennia* has a discontinuous range over the Neotropical, Sonoran and Holarctic regions. *Erythromma*, a characteristic Holarctic genus with two species in Chili, recalls the range of many other groups of animals.

Comparatively few widespread genera are confined to the old world. *Copera* is Oriental, Mascarene, and Manchurian; and *Pseudagrion* Oriental, Ethiopian, and Australian, entering the southern Holarctic. *Argiocnemis* and *Teinobasis* are Mascarene, Oriental, and Australian, while *Agriocnemis*, nearly allied to the former, is Ethiopian also.

Most of the fossil dragonflies of this sub-family are of Tertiary age, but a few are described from the Solenhofen rocks. It is interesting that a genus (*Megapodagrion*), now entirely Neotropical, should be represented in the Eocene beds of Wyoming, recalling the former northern range of many of the mammals now confined to Tropical America.

In the annexed table I have given the number of genera of each sub-family occurring in or peculiar to the various regions and sub-regions. In this table large genera are reckoned as peculiar, even if they cross with one or two species, the frontiers of their region into the neighbouring sub-region. The first numbers in each column indicate the genera occurring in the region or sub-region, the succeeding numbers (in brackets) indicate the peculiar genera.

	LIBELLULIDÆ.		ÆSCHNIDÆ.		AGRIONIDÆ.		TOTAL.
	Libellulinæ.	Cordulinæ.	Gomphlinæ.	Æschninæ.	Agrioninæ.	Cœnagrininæ.	
Neotropical, ..	42 (30)	4 (3)	18 (16)	8 (3)	10 (9)	40 (30)	122 (91)
Chilian, ..	4	2	7 (4)	2	0	4	19 (4)
Brazilian, ..	37 (13)	4 (2)	13 (5)	8 (2)	9 (9)	34 (14)	105 (45)
Mexican, ..	17 (1)	0	5	5	1	16	44 (1)
Antillean, ..	22 (2)	0	2	4	1	12	41 (2)
Sonoran, ...	14 (4)	7 (4)	9 (3)	4 (1)	2	11	47 (12)
Holarctic, ...	18 (5)	6 (3)	12 (4)	8 (5)	7 (4)	12 (1)	63 (22)
Canadian, ..	3	2	5 (1)	4	1	4	19 (1)
Siberian, ..	4	3	2	2	1	6 (1)	18 (1)
European, ..	6 (1)	4	4	3 (1)	1	9	27 (2)
Mediterranean,	12	3	5 (1)	4 (1)	2 (1)	9	35 (3)
Manchurian,	10 (2)	2	9 (2)	4 (1)	6 (3)	8	39 (8)
Ethiopian, ...	31 (14)	4 (2)	10 (6)	4 (1)	4 (2)	16 (7)	69 (32)
West African,	29 (12)	4 (2)	7 (4)	3 (1)	4 (2)	13 (4)	60 (25)
South African,	10 (1)	2	3	1	2	11 (1)	29 (2)
East African,	11 (1)	1	5 (1)	1	2	9	29 (2)
Mascarene, ..	19 (6)	3 (1)	2 (1)	2	1	14 (5)	41 (13)
Oriental, . ..	41 (12)	5 (1)	18 (13)	7 (3)	15 (13)	27 (13)	113 (58)
Hindustan, ..	19	2	10 (2)	3 (1)	8	11	53 (3)
Ceylon, ...	18	1	1	0	4	6	30
Indo-Chinese,	19	3	13 (2)	2	11 (1)	15 (2)	63 (5)
Indo-Malayan,	34 (7)	5	8 (2)	6 (3)	9 (2)	23 (4)	85 (18)
Australian, ..	28 (8)	6 (4)	5 (3)	9 (3)	0	23 (10)	71 (28)
Austro-Malayan	24 (2)	0	0	3	[1]	11 (4)	38 (6)
Australian, ..	12 (2)	6	4 (2)	5 (3)	0	10 (5)	37 (12)
Polynesian, ..	8 (1)	2	0	2	0	7 (3)	19 (4)
New Zealand,	1	1	1 (1)	0	0	2	5 (1)
Total genera of each subfamily, ..	114	23	55	24	33	91	340
Percentage peculiar to one or other of the regions,..	69·30	78·26	81·81	75	84·85	72·52	
Percentage of genera with wide range, ...	30·70	21·74	18·19	25	15·15	27·48	

The results of this table are interesting and suggestive. The largest and most dominant sub-families, the Libellulinæ and Cœnagrioninæ have the largest percentage of widely-ranging

genera. These groups, it will be remembered, are better represented in Tertiary than in Secondary rocks, and are clearly the most vigorous and flourishing branches of the order. The Æschninæ, a group which seems to have passed its zenith, and the Corduliinæ show a larger proportion of forms peculiar to various regions. Lastly, in the Gomphinæ and the Agrioninæ, with an excessively large percentage of genera of restricted range, we see the evidence of their geographical distribution strongly confirming the opinion of students of their structure, that they are the most primitive of the dragonfly sub-families. In several large genera, the American species largely outnumber those inhabiting the Old World. Such distribution appears to show an approach to that of those ancient groups which have become altogether extinct in the eastern hemisphere, while they still flourish in the great western continent.

Having given in the tables the distribution of the genera, so far as I have been able to ascertain the facts, it seems unnecessary to repeat the same information in maps. I have, therefore, thought it sufficient to give a single map which indicates generally the main features of dragonfly distribution over the earth's surface, showing the extent and overlapping of faunas rather than the boundaries of regions and sub-regions which will be sufficiently familiar to readers of the present Paper.

LVI.

APPLICATION OF THE PARALLELOGRAM LAW IN KINE-MATICS. By THOMAS PRESTON, M.A., F.R.U.I.

On a Fundamental Method in Kinematics.—In this note I wish to attract attention to a method of determining the accelerations of a moving point in terms of any system of coordinates, and the advantages which the method appears to possess lie not only in the ease and uniformity of its application to all systems of coordinates but also, and what is probably most important, in the directness with which what we might term the fundamental or physical condition of motion is employed and kept in view.

By way of a preliminary remark we may mention, that since acceleration is defined as rate of change of velocity, and since velocity possesses both magnitude and direction, it follows that an acceleration exists when the velocity changes either in magnitude or directions. For example, when a moving point describes a curve with constant speed its direction of motion changes from point to point, while its speed remains the same, and this is produced by an acceleration directed towards the concave side of the curve. This is mentioned, because beginners sometimes find a difficulty in understanding how it is that an acceleration exists when the speed of a moving point remains uniform (for example, in the case of a point describing a circle with uniform speed), and to such I think the difficulty will be at once removed if they keep in view the fact that

Fig. 1.

any quantity, such as a velocity, or acceleration, or a force, which can be compounded or resolved according to the parallelogram law, may be changed in direction or magnitude, or both magnitude and direction, by simply compounding it with another quantity of the same sort. For example, a force, P (fig. 1), if combined with another force, Q of properly chosen magnitude, will
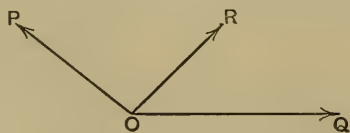
give a resultant of the same magnitude as P but differing in direction. The effect of Q in general, therefore, is to change the magnitude and direction of P; but it may be so chosen as to alter either of these and leave the other unchanged.

It is this principle of compounding and resolving according to the parallelogram law that underlies the whole science of Mechanics, and whenever we employ it we deal with the problem more nearly from first principles, and therefore keep in view more prominently the nature of the processes and assumptions by which we arrive at our final result.

As a first illustration of this principle of resolution, let it be required to write down the component velocities of a point parallel to the axes of reference when it is given that the point describes a circle round the origin with uniform angular velocity. In this case the velocity of the point is perpendicular to the radius vector OP (fig. 2), and proportional to it being equal to ωr, and therefore by the principle of resolution this may be replaced by a component velocity perpendicular to x, and proportional to x, together with a component perpendicular to y and proportional to y. That is, the velocity ωr perpendicular to r gives components ωx perpendicular to x, and ωy perpendicular to y. Hence, for the direction of rotation opposite to the hands of a watch the component velocities in the directions of the axes of reference are, obviously,
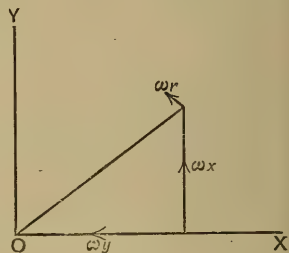
Fig. 2.

$$u = -\omega y, \quad v = \omega x.$$

We shall now employ the same method to determine the acceleration of a point P which describes a circle with uniform angular velocity. Let O be the centre of the circle, and P' a position of the point so close to P, that the arc PP' may be supposed to sensibly coincide with its chord. Then, since the velocity at P

Fig. 3.

is perpendicular to OP, and proportional to it, viz. ωr, and since the velocity at P' is perpendicular to OP' and proportional to it (viz. ωr
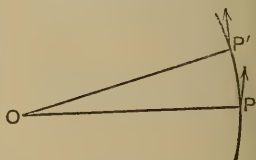
as before), it follows that the velocity at P' is the resultant of that at
P, compounded with a velocity perpendicular to PP', and propor-
tional to it, viz. $\omega \cdot PP'$. Remembering the definition of accele-
ration as rate of change of velocity, we find at once that the
resultant acceleration is perpendicular to the arc, and ω times the
rate at which the arc is being described, that is, $\omega v = \omega^2 r$. Thus the
centripetal acceleration in terms of the angular or linear velocity is

$$\omega v = \omega^2 r = \frac{v^2}{r}.$$

This is the fundamental proposition of the whole subject, and
in the following we shall make constant use of it. Expressed in
words it implies that when a point is describing a curved path the
accelerations directed towards the centre of curvature is ωv or $\omega^2 r$,
where ω is the angular velocity, and r the radius of curvature. It
may also be expressed as v^2/r, which is the square of the velocity
multiplied by the curvature, and shows how this centripetal accele-
ration at right angles to the direction of motion depends on the
curvature of the path that is on the angular velocity or the changing
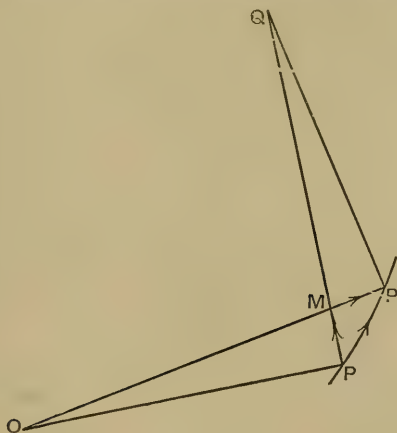
Fig. 4.

of the direction of motion. It is for this reason that when the
axes of reference are a mutually rectangular system the accelera-
tions parallel to the axes are independent of each other.

It is otherwise when we use polar coordinates, and to exemplify
this we shall apply our method to determine the accelerations
of a moving point, estimated at any instant, parallel to and
perpendicular to the radius vector. Let PP' (fig. 4), be an

element ds of the path of the point P, so that in going from P to P' both r and θ increase, the direction of positive rotation being opposite to that of the hands of a watch.

At P and P' erect perpendiculars to OP and OP' and let them meet at Q. Then, if $PP' = ds$, we have $PM = rd\theta$, and $MP' = dr$ so that the velocity $\dfrac{ds}{dt}$ along PP' is equivalent to a velocity $r\,\dfrac{d\theta}{dt}$ along PM together with a velocity $\dfrac{dr}{dt}$ along MP'. Hence, in estimating the acceleration along the radius vector we have to consider not only the velocity $\dot{r}$ along r, but also the velocity $r\dot{\theta}$ at right angles to it. The former gives an acceleration outwards along r measured by $\dfrac{d\dot{r}}{dt} = \ddot{r}$ and the latter gives a centripetal acceleration along r inwards measured by $r\omega^2 = r\dot{\theta}^2$. Consequently the whole acceleration along r is

$$\ddot{r} - r\,\dot{\theta}^2$$

The advantage of this method, besides its simplicity, lies in its bringing into prominence the meaning of the separate terms.

To obtain the acceleration at right angles to the radius vector we have in the direction PM a velocity $r\dot{\theta}$ which gives an acceleration in this direction equal to

$$\frac{d}{dt}\,(r\dot{\theta})\,;$$

further, we have a velocity $\dot{r}$ along MP' which gives an acceleration (v^2/ρ) towards Q measured by[1]

$$\frac{\dot{r}^2}{MQ} = \dot{r}^2 \div \frac{dr}{d\theta} = \dot{r}^2 \div \frac{\dot{r}}{\dot{\theta}} = \dot{r}\dot{\theta}\,;$$

consequently the whole acceleration at right angles to the radius vector is

$$\frac{d}{dt}\,(r\dot{\theta}) + \dot{r}\dot{\theta} = \frac{1}{r}\,\frac{d}{dt}\,(r^2\dot{\theta}),$$

which merely expresses that the moment of the acceleration round the origin is equal to the time rate of change of the moment of the velocity.

---

[1] This may be seen directly to be $\ddot{r}\dot{\theta}$, for the linear velocity along MP is $\dot{r}$, and the angular velocity round Q is $\dot{\theta}$.

Lemma.—Before going further it may be well to state the result made use of in the last investigation as a separate lemma for subsequent use. We have seen that

$$MQ = \frac{dr}{d\theta} = \frac{dr}{dt} \div \frac{d\theta}{dt} = \frac{\dot{r}}{\dot{\theta}};$$

and, since MQ is the radius of curvature of MP' regarded as an element of path described with the velocity $\dot{r}$, it follows that the radius of curvature of the radial velocity is equal to the radial velocity divided by the angular velocity, or

$$\rho = \frac{\dot{r}}{\dot{\theta}}.$$

In the general case of polar coordinates in three dimensions the acceleration can be written down with almost equal ease. In this case the sides of the element of volume are dr, $rd\theta$, and $r\sin\theta d\phi$ respectively, passing from the corner P (fig. 5) to the diametrically
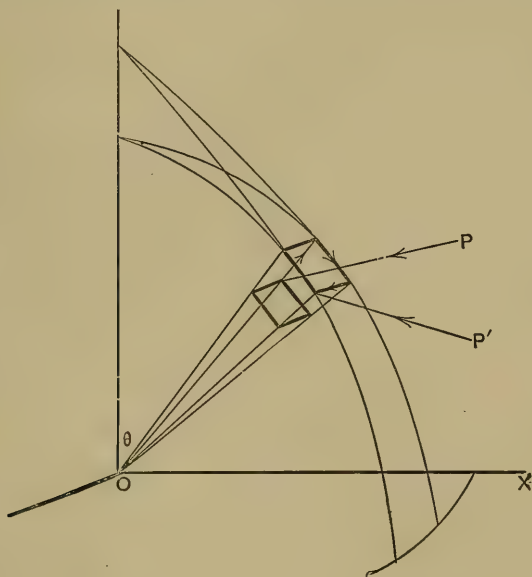
FIG. 5.

opposite corner P' in the direction in which r, θ, ϕ increase. In this case the velocity may be resolved into three components, $\dot{r}$, $r\dot{\theta}$, $r\sin\theta\dot{\phi}$ along the radius vector, along the meridian, and

perpendicular to these two directions respectively. We are now in a position to determine the accelerations in these directions.

To determine the acceleration along the radius vector we have, in the first place, from the radial component $\dot{r}$ an acceleration outwards along r equal to $\ddot{r}$. The second velocity component, namely the meridian component $r\dot{\theta}$, gives an acceleration (v^2/ρ) inwards along r equal to

$$-\frac{(r\dot{\theta})^2}{r} = -r\dot{\theta}^2.$$

and the third velocity component, $r\sin\theta\dot{\phi}$, gives an acceleration inwards equal to (v^2/ρ) or

$$-\frac{(r\sin\theta\dot{\phi})^2}{r} = -r\sin^2\theta\dot{\phi}^2.$$

The whole acceleration along the radius vector is consequently

$$\ddot{r} - r\dot{\theta}^2 - r\sin^2\theta\dot{\phi}^2 = \ddot{r} - r\,(\dot{\theta}^2 + \sin^2\theta\dot{\phi}^2).$$

In the same manner the same velocity components give at once, remembering our lemma, accelerations along the meridian measured by

$$\dot{r}^2 \div \frac{\dot{r}}{\dot{\theta}}, \quad \frac{d}{dt}\,(r\dot{\theta}), \quad -\frac{(r\sin\theta\dot{\phi})^2}{r\tan\theta},$$

and, therefore, the total acceleration along the meridian is

$$\frac{1}{r}\,\left\{\frac{d}{dt}\,(r^2\dot{\theta}) - r^2\sin\theta\,\cos\theta\dot{\phi}^2\right\}.$$

In the same way the acceleration perpendicular to the meridian plane is

$$\frac{1}{r\sin\theta}\,\frac{d}{dt}\,(r^2\sin^2\theta\dot{\phi}),$$

being the sum of the components

$$\dot{r}^2 \div \frac{\dot{r}}{\sin\theta\dot{\phi}}, \quad r\cos\theta\dot{\theta}\dot{\phi}, \quad \frac{d}{dt}\,(r\sin\theta\dot{\phi}).$$

In the case of cylindrical coordinates we proceed in the same manner.

In the same way if PP' (fig. 4) be taken as an element of an electric current, it may be replaced by two elements of the same strength along PM and MP', respectively, and the fundamental formulæ of Electrodynamics may be deduced at once.

LVII.

REPORT OF THE COMMITTEE consisting of PROFESSOR W. J.
SOLLAS, LL.D., F.R.S., R. LLOYD PRAEGER, B.A., B.E.,
A. F. DIXON, M.B., AND ALFRED DELAP, B.A., B.E.,
appointed by the Royal Dublin Society to investigate the recent
Bog-flow in Kerry. Drawn up by R. LLOYD PRAEGER and PRO-
FESSOR SOLLAS. (PLATES XVIII. AND XIX.)

THE daily newspapers of Tuesday, the 29th of December, 1896,
announced that, in the early hours of the morning of the previous
day, a bog, situated at the head of the Ownacree valley, seven
miles N.N.E. of Headford, near Killarney, had burst, and dis-
charged a fluid mass, which, pouring down the valley of the
Ownacree, had devastated the surrounding country in its course.

Without loss of time the Royal Dublin Society appointed a
committee, consisting of Professor W. J. Sollas, Mr. R. Ll. Praeger,
Dr. A. F. Dixon, and Mr. A. D. Delap, to investigate and to
report on the phenomenon. The committee left Dublin on the
afternoon of Friday, January 2nd, and devoted Saturday, Sunday,
and the early part of Monday to the work. They desire to
acknowledge in this place the kind assistance rendered them by
Mr. Maurice Leonard, J.P., acting for Lord Kenmare, on whose
estate the bog is situated.

The following summary comprises the results of their observa-
tions and inquiries, supplemented by information derived from
the full accounts which appeared in the Dublin press.

A dry summer had been followed by a wet autumn, and, about
nightfall on December 27th, a heavy downpour of rain set in, accom-
panied by a south-easterly gale. Somewhere between two and three
o'clock the following morning, the edge of the Knocknageeha bog,
which overlooks the Ownacree valley, gave way, and liberated a
vast flood of peat and water. There was no immediate warning of

the catastrophe, and no one witnessed the actual rupture. That the flood of escaping fluid did not at once acquire its full force is proved by the testimony of Mr. Arthur John Keeffe, as given in the *Freeman's Journal* of January 4th. He states that, driving to Killarney fair, his horse stopped near the bridge on the Quarry Lodge road, and could not be induced to proceed; he then jumped off the car, and found himself standing in mud knee-deep. After vainly endeavouring to cross the bridge, he retraced his steps and roused some neighbours. He returned with them in half-an-hour's time, to find that he could not approach within, as he states, a quarter of a mile of the bridge. There is an inexactitude, however, about this statement, as the total width of the flood at this point does not exceed the distance mentioned, viz. one quarter of a mile.

Although the outburst was clearly not instantaneous, it evidently proceeded with great rapidity, as is witnessed by the circumstances of a lamentable loss of life. The bog gave way along the line of a turf-cutting from 4 to 10 feet deep, parallel to which, and about 300 yards below it, runs the Kingwilliamstown road. A small stream, coming from the bog, passes under this road. Close by this stream, on the lower side of the road, was situated the house of Cornelius Donelly, Lord Kenmare's quarry steward; it was of the ordinary type, of one storey, with walls of rubble masonry and a thatched roof; it stood about 12 feet below the level of the road, and at a short distance from it, the intervening space being occupied by a garden. The house was entirely swept away; Cornelius Donelly, his wife, and family of six children all perished; the bodies of some of them, and those of their livestock, together with articles of furniture, were carried down the valley, and were found at various points along the course of the flood, a portion of one of the beds being picked up, a few days later, in the Lake of Killarney—fourteen miles away. From the fact that the whole family perished, and that those bodies which were recovered were without clothing, it would appear that the rapidity with which the flood rose was so great as to afford them no chance of escape.

The Flood.—After bursting from the face of the turf-cutting already mentioned, the first obstacle the flood encountered was

the road leading to Kingwilliamstown, which ran on an embank-
ment about 6 feet above the level of the cut-out bog; it over-
whelmed this for a width of a quarter of a mile, and continued
its course to the road to Killarney, a short distance below, pouring
as it passed, a small cataract of mud into the old quarry at the
cross-roads. The Carraundulkeen, a small streamlet, tributary
to the Ownacree, passes under the Killarney road, through a
culvert about 8 feet by 5 feet; this was speedily blocked with
masses of turf, and the rising flood poured across the road, carry-
ing away the tall hedges on both sides that stood in its course
on its eastern side. On both this and the Kingwilliamstown
road huge masses of the more coherent upper crust of the bog
were left stranded. A short distance further down, on the
northern side of the Carraundulkeen valley, is situated a valuable
limestone quarry, which the flood filled to a depth of 15 or 20
feet; as it impinged on the lower corner of the entrance, it
surged up in a great wave 3 or 4 feet above the highest level
within the quarry, which is marked as a horizontal line along
the quarry walls. Beyond the quarry it continued down the
valley for a straight run of three-quarters of a mile, to enter,
almost at right angles, the valley of the Ownacree or Quagmire
river. Checked, as it encountered the opposing side of this valley,
the flood rose along its middle line, where its velocity was greatest,
8 feet above its sides. A small cottage stands near by, and its
floor is 5 feet below the maximum height of the flood. It owes
its escape to the fact that it is situated about 100 yards on one side
of the middle line of the flow. After entering the main valley,
the flood continued its career for a mile and a half to Annagh-
bridge, where the Ownacree meanders through flat bog and
meadows. These, and the road which crosses the bridge, were
inundated, and the muddy fluid broadened out into a black lake,
half a mile in length by 600 yards in breadth. A breach was
made in the road close beside the bridge. On the margin of the
submerged flat stands the cottage of Jeremiah Lyne; he and his
family had a narrow escape. The flood, in its downward course,
encountered the back of the cottage, and rose against it 5 feet,
sweeping two haycocks, which stood behind the house round to the
gable. The family were awakened by water pouring in. They

were unable to unbar the door owing to the pressure of 3 feet of fluid, and escaped by climbing through the window and wading to higher ground.

Below Annagh Bridge, the force of the flood was less felt. At Barraduff Bridge, "Six-mile" Bridge of the Ordnance map, where the Ownacree joins the Beheenagh river, the Ownacree is 20 feet wide, and the flood rose 8 feet; below the junction the stream is 30 to 50 feet wide, and the flood rose 6 feet; at "Six-mile" Bridge it rose to the top of the arches, 10 feet above its normal level; at the bridge two miles below Headford, the level of the flood was about 4 feet above the stream, and finally at Flesk Bridge, near the Lake of Killarney, one foot.

The flood attained its maximum height during its first great outburst in the dark hours of Monday morning. At daybreak, the roaring flood of black fluid, bearing on its surface huge masses of the lighter crust of the bog, had already become confined to the central portions of the valley, but still ran across the road and over the site of Donnelly's house. The flow, which continued with constantly diminishing violence for the whole of Monday, was not regular, but intermittent, swelling and diminishing as fresh portions of the bog gave way, and slid downwards into the torrent. Every fresh outburst was accompanied by loud noises, likened by bystanders to the booming of big guns or the rumbling of thunder. Over the sides of the valley the settlement of the peaty part of the fluid had already taken place, and, as drainage continued, increased somewhat in consistency. The disruption of masses of bog continued at intervals down to Friday, January 1st. When we visited the scene on Saturday, January 2nd, the flow had lost its torrential character, but a turbid stream, many times increased beyond its usual volume, occupied the river bed. Mr. James Barbour, who visited the place on Saturday, January 8th, reports that one could then have stepped across the stream, so that by this time it must have shrunk to nearly its usual size.

The Bog before the outburst.—The district in which the bog is situated forms the southern portion of a high and undulating area of Coal-measures, generally bog-covered, and attaining a height of over 1200 feet, some miles to the north-west. That part of the bog in which the outburst took place is about 750 feet above the

sea ; it forms the watershed, and drains eastwards into the river Blackwater, and west into the Ownacree. To the north-east the bog descends in a gentle slope towards the Tooreencahill stream, a branch of the Blackwater ; to the north-west towards the main branch of the Ownacree, and westwards towards the Carraundul-keen streamlet, into which it burst. Judging from the size of the valley in which this branch flows, it would appear that the greater part of the bog drained into the last-mentioned stream. At the inquest evidence was given that a " wet vein " existed in the bog continuing the direction of this stream. It is of interest to observe that the bog rests partly on Coal-measures, and partly on Carboniferous limestone, which is brought up by an anticlinal, and separated from the Coal-measures by a fault, which runs for some miles east and west, through the very middle of that part of the bog which lies adjacent to the outburst.

The bog, like most others, possessed a convex surface ; it extended in three arms, which sloped downwards in the three directions of drainage already specified. In all other directions it is bounded by gently rising cultivated land. It was not drained by any superficial streams, nor was any large amount of water discharged at any point from beneath. The " wet vein " already mentioned was evidently a line of drainage.

The peasantry state that the surface of the bog was exceptionally soft ; they admit, however, they could walk across it in the middle of winter. According to the evidence of Cornelius Sullivan (*Freeman*, December 31st), the place was " shaky in patches, and persons crossing the bog could avoid these." The flora of the bog shows that it was no wetter than bogs usually are. The plants which form its surface are members of the normal bog-flora. The vegetation consists of a tangle of *Calluna Erica* (Ling), *Erica Tetralix* (Cross-leaved Heath), *Narthecium Ossifragum* (Bog Asphodel), *Scirpus cæspitosus* (Club-rush), and *Molinia varia* (Purple Melic grass), with the usual abundant undergrowth of bog-mosses, of which *Sphagnum rubellum* is the prevailing species, while *S. cuspidatum*, var. *plumosum*, fills the numerous shallow pools, which, as usual, were scattered over the surface. Tufts of the moss *Racomitrium lanuginosum* were frequent, and the lichen *Cladonia rangiferina* (Reindeer moss) was abundant, mixed with the hepatic

Pleurozia cochleariformis. The above list furnishes satisfactory evidence that the surface of the bog was not unusually wet; indeed, the plants characteristic of wet bogs, such as *Andromeda polifolia* and *Schollera Oxycoccus* (Cranberry), though searched for, were not to be found.

The bog had been cut for turf in two places—on the north-eastern slope, which faces towards the Blackwater, where the cuttings were of no great extent; and along the western edge, where, as already stated, they formed an irregular line, running parallel to the Kingwilliamstown road. It was from the latter cuttings that much of the local fuel was obtained. As regards these, Timothy Carey gave the following evidence at the inquest:— " The edge of the bog was not firm; we could cut only a depth of four sods, and a breadth of four sods from the edge. You would sink in the bog if you went in further; after a while, when the exposed place dried, you could cut down four sods more, and then you came to the clay."[1]   " For the last few years, they could not cut deep in the bog; it had a habit of closing in."[2]

The cutting does not appear to have been judiciously planned, except at the southern end, where it extended in wedge-shaped gashes into the bog; but for the rest of the distance it was cut in an irregular line, transverse to the line of drainage.

An evidently faithful description of the bog, as it existed in 1811, is given by Mr. Nimmo[3] in his account of the bogs of Kerry and Cork. It appears under the heading " No. 6 or the Quarries Bog "; the area of which is stated to be 2103·6 Irish, or 3407·5 English acres.

" The bog is at a high level, being about 650 to 700 feet above the sea, and is in this place on the summit of the county; its waters passing on the east to the Blackwater, and on the west to the Awinegrea and Flesk to the Lake of Killarney. It is mostly pretty firm and requires little more than surface drainage." Under the estimate of the cost of a scheme for draining the bog,

---

[1] *Freeman*, Dec. 31.   [2] *Irish Times*, Dec. 31.

[3] Appendix to Fourth Report of the Commissioners appointed to inquire into the nature and extent of the several bogs in Ireland, and the practicability of draining and cultivating them : ordered by the House of Commons to be printed 28th April, 1814, p. 84.

SCALE OF MILES

0   1/2   1   1 1/2   2
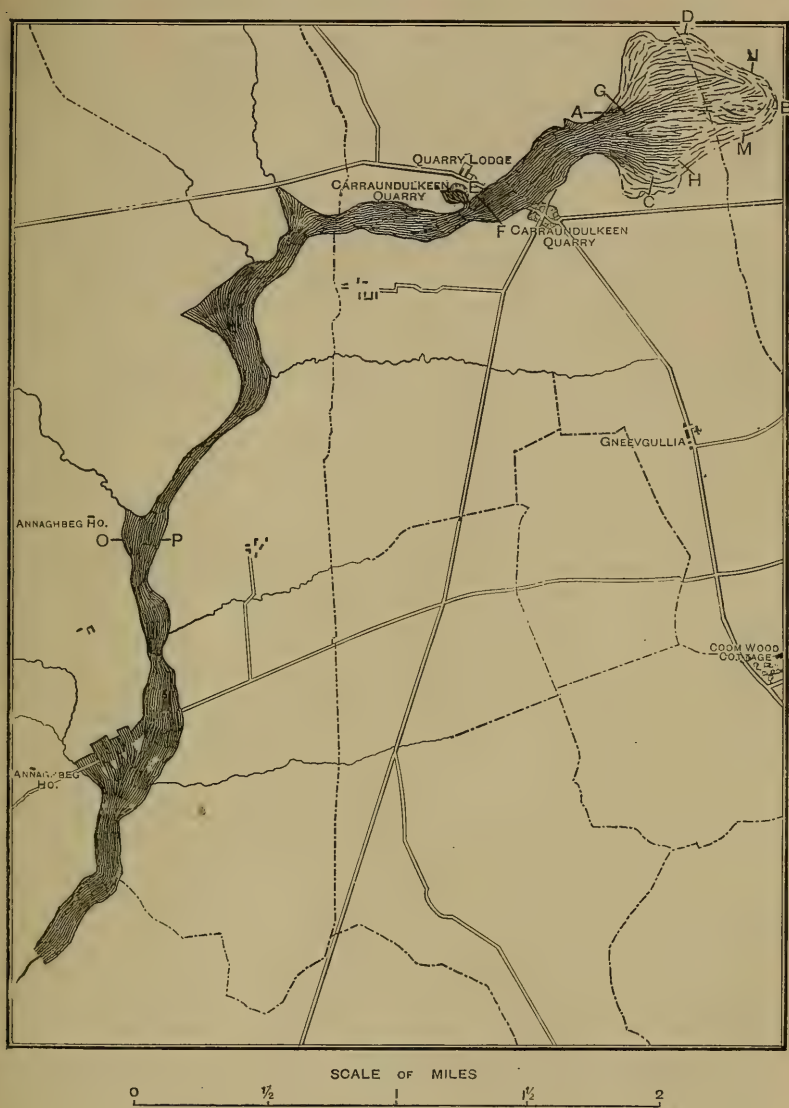
Fɪɢ. 1.

Map showing the subsided portion of the bog, and the area over which peat has been deposited in the valley of the Ownacree. The letters A to P indicate the directions in which the sections shown in figs. 2 and 3 were taken.

we find the following interesting item :—" Two cuts into a swamp on the summit, 304 perches at 3s. 6d., £53 4s."

The Bog after the outburst.—Mr. Leonard states that on visiting the bog at mid-day on Monday, about eight hours after the outburst, its surface for about a mile above the site of the turf-cutting was no longer convex but level. As the escape of fluid material continued, the surface correspondingly sank, till a shallow saucer-shaped depression was formed, opening by a narrow trough into the Carraundulkeen stream. At each side of the mouth of this trough there could still be seen the undisturbed ends of the turf-cutting; the central portion, for the width of a furlong, had disappeared. Looking eastwards from this point, a wide, broad valley appeared to extend upwards into the bog. On January 2nd, when we saw it, this depression was 7 furlongs in length by 5 furlongs wide, with a maximum depth of 28 feet. From careful inquiries it would appear that the former elevation of the centre of the bog above the undisturbed edge of the depression was about 7 feet, so that the total subsidence amounted to no less than 35 feet. The margin of this collapsed portion of the bog was clearly marked, so that we had no difficulty in tracing it on the 6-inch map, from which the plan (fig. 1) accompanying this Report is reduced. The slope near the side was comparatively steep, lessening towards the middle; the steep margin was marked by concentric fissures, which, when of sufficient width, were occupied by great masses of " sludge" which had risen from below. Near the margin, the area of these crevasses, as compared with that of the still remaining upper surface, was about 1 : 3; the proportion increased to about 2 : 1 near the centre, where also the fissures were no longer concentric, owing to the fact that a definite flow of the whole mass of the bog had taken place down the valley. Over the two areas, marked on the map by close parallel lines, the surface had entirely disappeared. Walking round the margin of the depressed area, it was observed that, in addition to those portions which originally sloped towards the Ownacree, other adjoining areas, which previously had sloped towards the east and north, had shared in the general subsidence, and now formed a part of the newly-formed valley which we have described as opening to the westward through the former turf-cutting. This curious feature will be

clearly seen from the sections of the bog given in figs. 2 and 3. A striking indication of this reversal of slope was furnished by several shallow surface drains which had been cut in order to dry the surface of the bog for turf-cutting at its eastern extremity. These, when made, had a slope of one in forty towards the Blackwater valley; they were now broken across, so that what had been the upper half sloped with an equal gradient towards the Ownacree. It was along the southern edge of the basin that the greatest amount of marginal disturbance had taken place, the proportion of crevasses to crust here being quite 2 : 1. This appears to have been the shallowest portion of the bog; several ridges of the underlying gravel had somewhat disturbed the general subsidence of the peat. The portion overlying the crests of the ridges had remained *in situ*, while that on their slopes had broken away on both sides, and flowed down through the depression between them. Soundings with a pole in these depressions showed hard bottom at from 5 to 8 feet. This was the only place where an 8-foot pole gave an indication of bottom. Owing to the increase in the number and width of the crevasses, on entering the depression from its margin, it was quite impossible to make any observations for more than 20 or 30 yards inwards from the edge. But there appears to be no doubt that along the line of greatest depression, the thick covering of bog had been entirely removed; in some places the hard bottom could be seen.

Effects of the Flood.—Immediately above the Kingwilliamstown road we pass from the area of subsidence to the region of flow. The flood has left behind it, in the upper portion of the valley, a deposit of peat averaging 3 feet in thickness, here as everywhere contrasted by its black colour with the grass land or other surface on which it rests. Its compact convex margin, like that of out-poured oatmeal porridge, often 2 feet in height, serves equally well to define it; so that it was an easy task to determine and map the high-water level of the flood. The surface of the deposit was everywhere broken by great roots and trunks of Scotch firs, which, in their enormous numbers, bore convincing testimony to the evisceration which the bog had undergone. The appearance of this extensive sea of black peat, with its protruding stumps of blackened trees, overlying fertile fields, was a sight melancholy in the extreme.
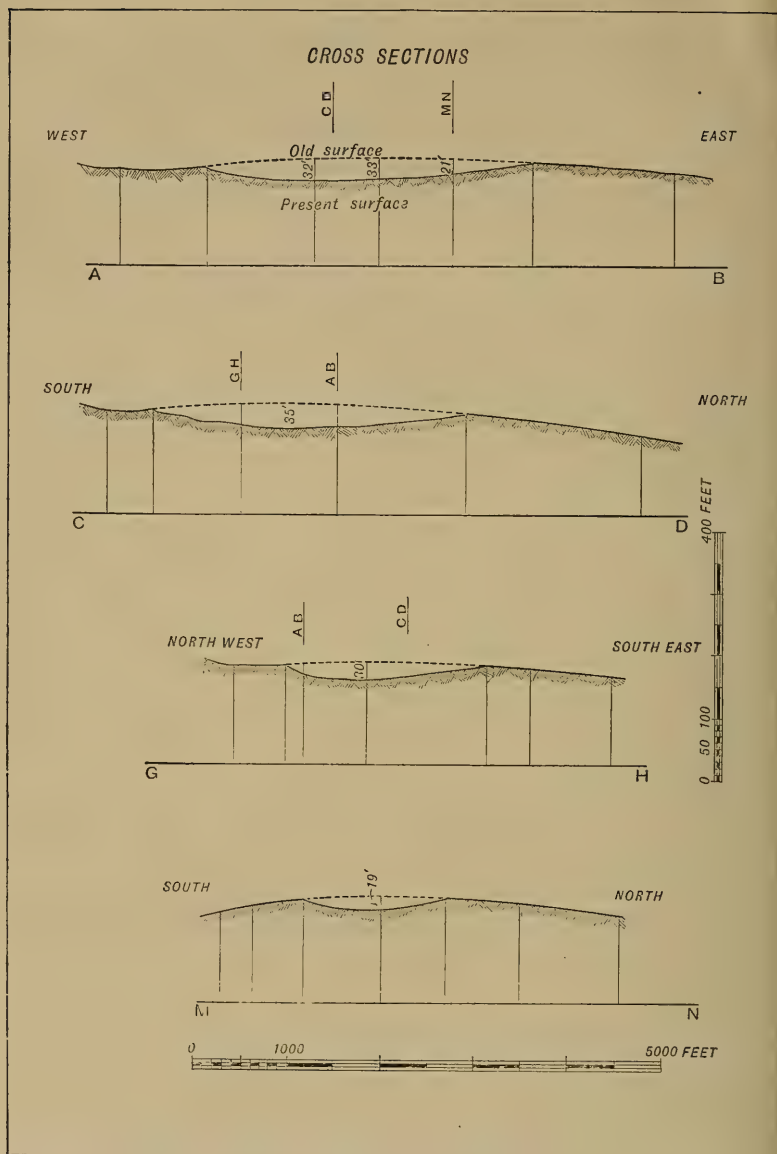
Fig. 2.

Sections through the bog of Knocknageeha.   Vertical scale, 6 times the Horizontal

LONGITUDINAL SECTION
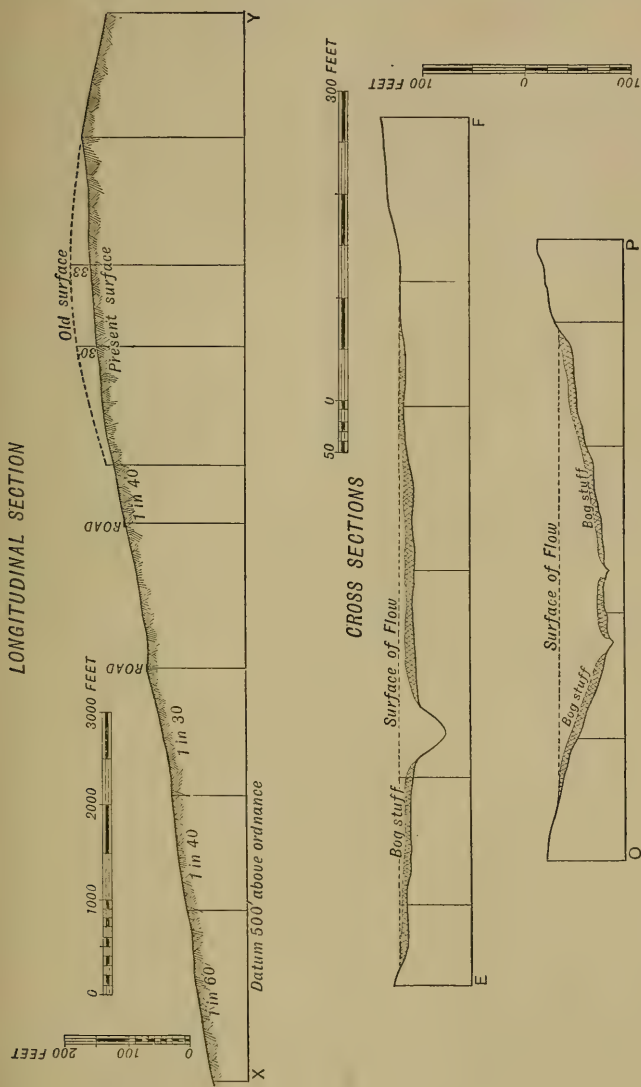
CROSS SECTIONS

Fɪɢ. 3.

Longitudinal section through the subsided area and the course of the flood. Cross-sections across the valley of the Ownacree, to show the height attained by the flood and the deposit of peat.

The presence of so much floating timber in the waters of the flood must have greatly enhanced its destructive power. One of the largest of these trees, a huge stump with roots 12 feet across, was seen lying some distance up the course of a tributary stream, and on the top of its overhanging bank, at a distance of two and a half miles from the scene of the outbreak.

The erosive effects on the bed of the Ownacree are well marked. We observed places where it had been lowered 6 feet; *e.g.* at a spot about half a mile from Annagh-bridge; a lane, which had extended across this as a shallow ford, had been cut through by a trench, 20 feet in width and 6 feet in depth. In other places the stream has cut for itself a new course.

The lamentable fate which overtook the Donelly family has been already alluded to. Many farmers have suffered serious loss by the tearing up and washing away of their potato pits, which were situated near the banks of the stream. The filling up of the limestone quarry is a serious inconvenience; for, although the work of clearing it out has been already commenced, and it will ultimately be worked as before, it must remain useless for some time. No other quarry exists in the neighbourhood, and lime is the only manure in universal demand. The roads can be cleared without much difficulty : the breaches made in them are not serious. The farmers will feel most seriously the loss of their land. On most of the holdings the best land was situated along the river banks; and, in the upper portions of the valley, this is now covered to a depth of 3 feet with a solid deposit of peat. At Annagh-bridge the average depth has decreased to 2 feet ; here the deposit is of a finer grain and more liquid. According to the inquiries made by the police, in the four townlands which occupy the east bank of the river between the scene of the outburst and a point a little below Annagh-bridge, close on 300 acres of land have been thus buried.[1] The tenants being all small holders, the loss of their best grazing has ruined them.

Premonitory Sounds.—Strange and contradictory rumours are prevalent among the peasantry as to whether any symptoms of the approaching catastrophe were noticed. Sergeant King, R.I.C., states positively that he and other officers on patrol heard rumbling

---

[1] *Freeman's Journal*, January 2nd.

noises some days before the occurrence. Further, it is certain that some of the peasantry were so alarmed by sounds, which they attributed to the "banshee," that the parish priest was sent for to pray with several families.

The evidence as to whether the actual bursting of the bog was accompanied by sounds is conflicting. Some state that they were awakened by a loud roar; others, including Mr. Mac Sweeney, of Quarry Lodge, slept as usual. But this negative evidence is of little or no value; for, in one instance, the flood passed within fifty yards of a cottage, breaking down and sweeping away the trees of the adjacent haggard, without arousing the occupants.

The phenomena attendant on or preceding the catastrophe, to which special attention may be directed, are the following :—

1. A dry summer was followed by a spell of wet weather, which commenced in September; and heavy rain fell immediately before the outburst.

2. An earthquake, which had its epicentre situated in Wales, or on the borders of the principality, occurred on December 15th, and is said to have been felt in Miltown-Malbay and other places in Ireland. This preceded the rupture of the bog by five days.

3. A fault trending from east to west crosses the collapsed area of the bog; and the Coal-measures, which form high ground to the north, dip towards it, *i.e.* southwards.

4. The stream of the Carraundulkeen was continued as a "wet line," or line of drainage, into the bog. At the origin of this was a swamp.

5. The neck of the bog was cut through by a working face, which thus crossed the line of drainage.

6. The centre of the collapsed portion of the bog stood, before the outburst, 7 feet higher than the sides.

7. The bog was disrupted along the line of peat-cutting, and liberated a deluge of water charged with peat. The volume of the discharged material we estimate to have amounted to about six million cubic yards.

8. As a consequence of this discharge the crust of the bog subsided; so that, after the lapse of some days, its centre had

fallen 35 feet below its original level, forming a depression with a maximum depth of 28 feet.

It is obvious that, before the outbreak, the condition of the bog was that of a viscous fluid enclosed within a resistant wall. The pressure of the fluid and the tension of the envelope were then in equilibrium. Owing to an increase in pressure or a decrease in the tensile strength of the containing wall, this equilibrium was destroyed, the envelope was ruptured at its weakest part, and the viscous fluid, under a head of pressure rushed down the inclined surface provided by the natural drainage of the country.

Before entering further into the discussion of the causes which led to the outburst, it will be convenient to present here information we have collected concerning similar occurrences which have taken place in the past. We give first a list of those which have affected the bogs of this country; they are arranged in chronological order.

Account of Bog Flows in Ireland.

A.D. 1697, June 7, *Kapanihane Bog, Co Limerick, near Charleville.*—This occurrence is so quaintly described in a letter dated June 7, 1697, that it is worth quoting *verbatim et literatim* :—

" On the 7th Day of *June,* 1697, near *Charleville,* in the County of *Limerick,* in *Ireland,* a great Rumbling, or faint Noise was heard in the Earth, much like unto a Sound of Thunder near spent ; for a little Space the Air was somewhat troubled with little Whisking Winds, seeming to meet contrary Ways : And soon after that, to the greater Terror and Afrightment of a great Number of Spectators, a more wonderful thing happened ; for in a Bog stretching North and South, the Earth began to move, viz. Meadow and Pasture Land that lay on the side of the Bog, and separated by an extraordinary large Ditch, and other Land on the further side adjoining to it ; and a Rising, or little Hill in the middle of the Bog hereupon sunk flat.

" This Motion began about Seven of the Clock in the Evening, fluctuating in its Motion like Waves, the Pasture-Land rising very high, so that it over-run the Ground beneath it, and moved upon

its Surface, rowling on with great pushing Violence, till it covered the Meadow, and is held to remain upon it 16 Feet.

" In the Motion of this Earth, it drew after it the Body of the Bog, part of it lying on the Place where the Pasture-Land that moved out of its Place it had before stood; leaving great Breaches behind it, and spewings of Water that cast up noisom Vapours : And so it continues at present, to the great Wonderment of those that pass by, or come many Miles to be Eye-witnesses of so strange a thing."

This communication was accompanied by a map and detailed description by John Honohane.[1]

A.D. 1708, *Castlegarde Bog, County Limerick.*—The Castlegarde bog, or as it was then called Poulevard, moved along a valley and buried three houses containing about twenty-one persons. It was a mile long, a quarter mile broad, and about 20 feet deep in some parts. It ran for several miles, crossed the high road at Doon, broke through several bridges, and poured into the Lough of Coolpish.[2]

A.D. 1745, March 28.—*Bog of Addergoole, Dunmore, County Galway.*—About mid-day, after a heavy thunder-shower, about 10 acres of bog, the front of which was being cut for turf, moved forward and down the course of a stream, and subsided upon a low pasture of 30 acres by the river side, where it spread and settled, covering the whole. The stream, thus dammed back, rose till it formed a lake of 300 acres, which, by the cutting of a channel, was subsequently reduced to 50 or 60 acres. This area, together with the 30 acres of meadow over which the bog spread has been destroyed for purposes of husbandry.[3]

A.D. 1788, March 27.—*Bog near Dundrum, County Tipperary.*— " A large bog of 1500 acres, lying between Dundrum and Cashel, in the county of Tipperary, began to be agitated in an extraordinary manner, and to the astonishment of and terror of neighbour-

[1] Philosophical Transactions, vol. xix., pp. 714–716, October, 1697 ; and Boate, Molyneux, and others, a Natural History of Ireland, p. 113, 1755.

[2] *Dublin Evening Telegraph,* 2nd January, 1897.

[3] Ouseley, Trans. R.I.A., vol. ii., Science, pp. 3-5, plate I., 1788.

ing inhabitants.   The rumbling noise from the bog gave the alarm, and on the 30th it burst, and a kind of lava issued from it, which took its direction towards Ballygriffen and Golden, overspreading and laying waste a vast tract of fine fertile land belonging to John Hide, Esq.   Everything that opposed its course was buried in ruins.   Four houses were totally destroyed, and the trees that stood near them torn up by the roots.   The discharge has been incessant since the 30th, and how far it will extend cannot at present be determined."[1]

A.D. 1809, 16th December.—*Bog of Rine, Camlin River, Co. Long-ford.*—"In the night, during a thunderstorm, about 20 acres of the bog burst asunder in numerous places, leaving chasms of many perches in length, and of various breadths, from 10 feet to 3 inches.   The rifts were in general parallel to the river, but in some places the smaller rifts were at right angles to it; not only the bog, but the bed of the river was forced upward; the boggy bottom filling up the channel of the river, and rising 3 or 4 feet above its former banks.   In a few hours 170 acres of land were by these means overflowed, and they continued in that state for many months, till the bed of the river was cleared by much labour and at considerable expense."   The bog had been an unusually wet one.   It did not sink in any particular place. "Several earthquakes were felt in distant countries about 16th December, . . . and it is not absolutely impossible that a communication may exist between them" [the earthquake and the bog-slide.][2]

A.D. 1819, January.—*Owenmore Valley, Erris, Co. Mayo.*—"A mountain tarn burst its banks, and heaving the bog that confined it, it came like a liquid wall a-down, forcing everything along, boulders, bog timber, and sludge, until, as it were in an instant, it broke upon the houses [of a small village], carrying all before it, stones, timbers, and bodies, and it was only some days after, that at the estuary of the river in Tullohan Bay, the bodies of the poor people were found."[3]

[1] *Gentleman's Magazine*, vol. lviii., p. 355, 1788.

[2] Edgeworth, App. 8 to 2nd Report of Bog Commission, p. 176, 1811.

[3] Otway, "Sketches in Erris and Tirawley," p. 14, 1841.

A.D. 1821, June 26.—*Bog of Kilmaleady, near Clara, King's Co.*—The excellent report on the outbreak of this bog, communicated to the Royal Dublin Society by Sir Richard Griffith, has supplied us with the following excerpts :—

" The bog of Kilmaleady, from whence the eruption took place, situated about two miles to the north of the village of Clara in the King's County, is of considerable extent ; it may probably contain about 500 acres ; in many parts it is 40 feet in depth, and is considered to be the wettest bog in the country. It is bounded on all sides, except the south, by steep ridges of high land, which are composed of limestone gravel, and beneath of cavernous limestone rock, containing subterranean streams ; but the southern face of the bog is open to a moory valley, about a quarter of a mile in breadth, which, for nearly half a mile in length, takes a southern direction in the lands of Lisanisky, and then turns at right angles to the west, and continues gradually widening for upwards of two miles. . . . The bog of Kilmaleady, like all other deep and wet bogs, is composed for the first eight or ten feet from the surface downwards of a reddish brown, spongy mass, formed of the still undecomposed fibres of the bog moss (*Sphagnum palustre*), which, by capillary attraction, absorbs water in great quantity. Beneath this fibrous mass, the bog gradually becomes pulpy, till, at length, towards the bottom, it assumes the appearance, and, when examined, the consistence, of a black mud, rather heavier than water.

" The surface of the bog of Kilmaleady was elevated for upwards of 20 feet above the level of the valley, from which it rose at a very steep angle; and its external face, owing to the uncommon dryness of the season, being much firmer than usual, the inhabitants of the vicinity were able to sink their turf-holes, and cut turf at a depth, of at least 10 feet beneath the surface of the valley, and, in fact, until they reached the blue clay which forms the substratum of the bog. Thus the faces of many of the turf-banks reached the unusual height of 30 feet perpendicularly : when at length, on the 19th day of June, the lower pulpy and muddy part of the bog, which possessed little cohesion, being unable to resist the great pressure of the water from behind, gave way, and, being once set in motion, floated the upper part of the bog, and continued to move with astonishing velocity along the

valley to the southward, forcing before it not only the clamps of turf, on the edge of the bog, but even patches of the moory meadows, to the depth of several feet, the grassy surface of which heaved and turned over almost like the waves of the ocean; so that, in a very short space of time, the whole valley, for the breadth of about a quarter of a mile between the bog-edge and the base of the hill of Lisanisky, was covered with bog to a depth of from 8 to 10 feet, and appeared everywhere studded with green patches of moory meadow. . . . A considerable deposit of heavy, black bog-mud, . . . at present fills the bottom of the stream. . . .

"In the centre of the bog, for the space of about one mile and a-half in length, and a quarter of a mile in breadth, a valley has been formed, sloping at the bottom from the original surface of the bog to a depth of 30 feet, where the eruption first took place. In this valley or gulf there are numberless concentric cuts or fissures filled with water nearly to the top.

"The valley between the edge of the bog and the road of Kilbride, for a length of half a mile, and an extent of between 60 and 80 acres, may be considered as totally destroyed. It is covered by tolerably firm bog from 6 to 10 feet in depth, consisting at the surface of numberless green islands, composed of detached parts of the moory meadows, and of small rounded patches of the original heathy surface of the bog, varying from 2 to 10 feet in diameter, which are separated from each other by brown pulpy bog; and the bed of the original stream is elevated to about 8 to 10 feet above its former course, so as to flow over the road. . . . The whole distance which the bog has flowed is about 3 miles in length, namely one mile and a half in the bog, and the same distance over the moory valley; and the extent covered amounts to about 150 acres."[1]

Sir William Wilde gives the following additional particulars taken from the daily press of the time:—

"At 7 p.m., of the evening of the 26th of June, the south front of the bog of Ballykillion, or Kilnalady, gave way to a depth of 25 feet, and, with a tremendous noise, commenced to move down

---

[1] Journal of the Royal Dublin Society, vol. i., pp. 141–144 and map, 1858.

the valley at the rate of about 2 yards an hour, with a front 200 yards wide, and about 8 feet deep. . . . It continued to move for more than a month.

"About the same time the Ferret bog, about 16 miles north-east of Kilnalady, was strongly agitated, boiling up to a great height."[1]

A.D. 1821, September. *Joyce Country, County Galway.*— "Upwards of a hundred acres of land, on which crops were growing and several families resided, were heard to emit a sound resembling thunder; the earth then became convulsed, and eventually this large tract moved down towards the sea, leaving the whole route over which it passed a complete waste."[2]

A.D. 1824, December 22. *Bog of Ballywindelland, Coleraine.*— A portion of this bog containing 80 or 100 acres gave way and passed into an adjoining valley; it gradually advanced on the firm land, during the day, at the rate of 2 feet per minute.[3]

A.D. 1831, January. *Bog near Geevagh, Co. Sligo.*—"After a sudden thaw of snow, the bog between Bloomfield and Geevah gave way; and a black deluge, carrying with it the contents of 100 acres of bog, took the direction of a small stream, and rolled on with the violence of a torrent, sweeping along heath, timber, mud, and stones, and overwhelming many meadows and arable land. On passing through some boggy land, the flood swept out a wide and deep ravine, and a part of the road leading from Bloomfield to St. James's Well was completely carried away from below the foundation for the breadth of 200 yards."[4]

A.D. 1835, Sept. 17. *Fairloch Moss, Randalstown, Co. Antrim.* (A very large bog overlooking a valley.)—All day a portion of it swelled up till the convexity was 30 feet in height; at 5 p.m., with a sound like a loud, rushing wind, it sank several feet, and a collection of tufts, mud, and water moved N.E., not rapidly, and soon stopped. It swelled up again, and about midday on the 19th, it again burst with a similar noise, and the flow crept on till the 21st, when it ceased

[1] Census of Ireland for the year 1851, part v., vol. i., 1856, pp. 189, 190.
[2] *Ibid.*, p. 90.   [3] *Ibid.*, p. 198.
[4] Lyell, "Principles of Geology," 10th ed., vol. ii., p. 504.

till the 23rd, being interrupted by ditches; on the 23rd, at 3 p.m., it suddenly rushed forward. Continuing, it surrounded a cottage 10 feet deep, rose over the Belfast-Londonderry coach road, crossed it with a width of 300 yards, and poured over the far bank in a cascade, and continued down the valley till it reached the River Maine, which it dammed temporarily, and killed all the fish. The flow into the Maine did not cease till Sept. 28. The deposited area of bog was three-quarters of a mile long, and 200 to 300 yards wide, with a maximum depth of 30 feet. The place where the bog had swelled up 30 feet, afterwards sunk 20 feet below its original level, and a small pool occupied the hollow.[1]

A.D. 1840, January. *Bog of Farrendoyle, Kanturk, Co. Cork.* —The bog was 10 feet in thickness, resting on a substratum of yellow clay; the pent-up water undermined a prodigious mass of bog, and bore it buoyantly on its surface; twenty acres of valuable meadow were covered, and a cottage was propelled and engulfed; a quarter of a mile of the road, from Kanturk to Williamstown, was covered 12 to 30 feet deep.[2]

A.D. 1870, December 14, 9 a.m. *Bog, near Castlereagh, Co. Roscommon.*—The bog is situated 5 miles north-east of Castlereagh, on the watershed of the river Suck and the Owenna-foreesha, a tributary of Lough Gara; it overlies cavernous limestone. The eruption took place from the face of a turf-cutting, which was from 12 to 15 feet in height. A very rapid flood of peat and water poured forth, bearing on its surface large masses of the crust of the bog; it rose 10 feet over Baslick Bridge, and left a deposit of peat, which covered 165 acres of low ground and extended for some 6 or 7 miles down the valley of the Suck. A valley was formed in the peat bog half a mile in length and 20 feet deep.[3]

A.D. 1873, October 1. *Bog 3 miles east of Dunmore, Co. Galway.* —The bog was connected with the Dunmore river by the Carrabel, a small stream. It was considerably elevated above the

---

[1] Hunter, Magazine of Nat. Hist, vol. ix., May, 1836, pp. 251–261.

[2] *Freeman's Journal*, January 3, 1840 (copied from the *Cork Standard*).

[3] Report to the Board of Public Works, by Mr. Forsyth, 26th and 28th January, 1871.

surrounding country, its edges presenting the appearance of high turf banks. "A farmer digging potatoes suddenly observed a brown mass slowly approaching. Leaving his spade in the ground, he went for the neighbours, and on his return the mass of moving bog had half covered his potato field, and completely hidden his corn field from sight, except a few stacks which remained on a knoll, an island in the midst of a scene of desolation."[1] The bog slowly flowed down the valley of the Dunmore, burying three farm-houses, and covering about 300 acres of pasture and arable land, 6 feet deep. The peat was cut along a perpendicular face, 25 to 30 feet in height, which extended down to the underlying gravel. It was from this cutting that the outburst took place. The flood of peat and water moved rapidly at first, but afterwards slowly, and continued in movement for 11 days. It carried away roads and bridges. The subsided portion of the bog extended eastwards from the face of the cutting for a distance of a quarter of a mile; its greatest breadth measured also a quarter of a mile : down the middle, a valley from 20 to 25 feet deep was formed, and about the sides the crust was torn asunder. The numerous crevasses so formed were filled to the top with black peaty fluid.[2]

A.D. 1883, January 25. *Bog near Castlereagh, Co. Roscommon.* —"The bog was situated between the villages of Moor and Baslick ; in about two hours, it moved a mile in a south-westerly direction towards the River Suck ; after a short interval, the movement continued, some 4000 acres of land were covered, three houses had to be deserted, several roads were blocked ; the Ballinagare-road being covered 15 feet deep. Eleven or twelve years ago the Tulla bog, situated about a quarter of a mile from the scene of the present outbreak, burst and discharged itself into the river Suck."[3]

A.D. 1883, January 30. *Bog near Newtownforbes, Co. Longford.*—"A bog near Newtownforbes has commenced to migrate, covering turf and potatoes."[4]

---

[1] Savage, " Picturesque Ireland," pp. 234-235, illustr. (*n. d.*).

[2] Report to the Board of Public Works, by Mr. Forsyth, 31st October, 1873.

[3] *Freeman's Journal,* January 27, 30, and 31, 1883.

[4] *Ibid.,* January 31, 1883.

A.D. 1890, January 27. *Bog at Loughatorick North, Co. Galway.*—The bog is situated in the townland of Loughatorick North, on the Slieve Aughty Mountains, nearly on the watershed, and 300 feet above Ballinlough Lake, which lies N.E., and into which the bog drains by a small river. The bog consists of two portions, separated by a narrow neck, where exposed rock was seen after the outburst. The upper and larger part is 70 acres in extent, the lower only 15 acres. The latter began to move 3 days before the upper portion: in its centre was a small lake to which an underground stream could be traced; after the outburst, this lake became dry. After a fall of snow, a sudden thaw set in on the 24th January; three days later a movement of the bog commenced, and continued till 1st February. Great masses of peat were carried away by the black flood into the Ballinlough Lake, which was nearly filled with peat and the out-washed trunks of trees. The lowlands were covered with peat over an area of 100 acres, and for a depth of 12 inches. Traces of the flood were visible to a height of 6 or 7 feet on the trunks of trees which stood in its course. The upper part of the bog subsided from 10 to 15 feet; its margins were much rent with fissures.[1]

1895, August 9. *Dungiven Bog, Co. Derry.*—The site was in the townland of Briskey, at the east slope of Benbradagh, an extensive mountain bog 10 to 30 feet in depth, sloping at a gradient of about 1 in 12. Where the burst occurred a small stream runs underground for about a quarter mile, the ground above it being firm, so that cattle grazed on it. On the evening of August 9th there was a thunderstorm, but not accompanied by any excessive rainfall. The weather during the summer had been normal. In the night, probably before midnight, between 2 and 3 acres of bog gave way. For some 40 yards length at its lower end, the bog burst out entirely. Over the rest a tapering area 300 feet wide by 600 long, the ground subsided about 10 feet, leaving great blocks of the solid crust, broken up in a fantastic way. A very considerable flood of water and peat poured down the stream, which eventually joins the River Roe. No damage was done, as the gradients are steep, and the land not under cultivation, but a

---

[1] Report to the Board of Public Works, by Mr. A. T. Pentland, 24th November, 1890.

cottage situated beside the stream 1 mile below the scene of the outburst narrowly escaped being washed away. A deposit of peat was left on the banks of the stream for a considerable distance. There is evidence of several similar slides having taken place in the district.[1]

Outside Ireland the bursting of bogs appears to be a phenomenon of great rarity. Klinge, in a valuable Paper on bog eruptions states that, after a diligent search through European literature, he has been able to discover only two examples that did not occur in this country. To these we are not able to add more than two others. Abstracts of the accounts of these occurrences are given below in chronological order.

Account of Bog-Flows elsewhere than in Ireland.

A.D. 1763, autumn. *Stuckhauser bogs, Treuenfeld, Duchy of Oldenburg.*—Lasius states[2] that an outburst of this bog took place, similar to that of Tullamore, but of less extent; it lies over the ordinary marsh floor, which is impervious to water, and is more than 20 feet deep. "The summer was exceedingly wet, and doubtless this is the explanation of the occurrence."

A.D. 1772, December 16. *Solway Moss, Cumberland, England.*—Lyell states that the bog, on December 16th, 1772, having been filled like a great sponge with water during heavy rains, swelled to an unusual height above the surrounding country, and then burst. The turfy covering seemed for a time to act like the skin of a bladder retaining the fluid within, till it forced a passage for itself, when a stream of black half-consolidated mud began at first to creep over the plain, resembling in its rate of progress an ordinary lava-current. No lives were lost, but the deluge totally overwhelmed some cottages, and covered 400 acres. The highest parts of the original moss subsided to the depth of about 25 feet, and the height of the moss, on the lowest parts of the country which it invaded, was at least 15 feet.

---

[1] Information supplied by Mr. H. C. Moore, C. E., Dungiven.
[2] Lesquereux, Untersuchungen über Torfmoor: German edition by Lengerke, with remarks by Sprengel and Lasius, 1847, p. 165, Anmerk.

A.D. 1871, November 29.   *Stanley, Falkland Isles, off Cape Horn.*
—"Just after midnight one of the inhabitants was awakened to
find that his house was surrounded by a black moving mass of
peat, several feet in height, and travelling down the hill at about
four or five miles an hour : following up the course which the slip
had taken, the hill presented a curious appearance ; from the peat-
bank down to the brow of the hill, a distance of about 250 yards,
the surface peat lay in confused heaps, direct from the opening of
the bog.   The water, or liquid peat, travelled over the ground
faster than the heavier bodies, which were left standing 3 or 4 feet
above the level of the ground.   Proceeding to the top of the bog,
I found a depression extending over 9 to 10 acres of ground, the
edges cracking and filling up with water." . . .   An endeavour
to drain the bog by cutting a trench did not succeed, "owing to
the soft peat welling up from the bottom and filling the trench
again."[1]

A.D. 1886, June 2.   *Stanley, Falkland Isles.*—A second outbreak
of the same bog took place 200 yards westward of the scene of the
previous slip.   A stream of half liquid peat, over 100 yards in
width, and four or five deep, flowed suddenly through the town
into the harbour, blocking up the streets, wrecking one or two
houses in its path, and surrounding others, so as to imprison their
inhabitants.   One child was unfortunately smothered in the peat,
and an old man is reported to be missing.   The slip is assigned to
the unusually heavy rains which fell during the few previous
days, and which the drains constructed by Mr. Bayley in 1878
proved insufficient to carry off. [2]

On comparing these records with each other, and with the
account already given of the recent catastrophe, a close general
similarity will readily be perceived to characterize them.

The recorded outflows differ partly in magnitude, but chiefly
in the rapidity of flow of the escaping material.   The rate of flow

---

[1] Extracts from a letter by Acting Governor Bailey to Governor Callaghan.
Quarterly Journal of the Geological Society, vol. xxxv., Proceedings, pp. 96, 97,
1879.

[2] Extracted from a letter by Lieut. Governor of the Falkland Islands, Arthur
Barkly, to the Rt. Hon. Earl Granville.   Quarterly Journal of the Geological Society,
vol. xliii., Proceedings, p. 2, 1887.

is evidently a function of the slope of the ground and the viscosity of the fluid, and the latter depends on the ratio between the amount of water and of solid contents present in the moving material. A difference also exists in the proportion of solid crust to liquid contents. The largest proportion of solid material is met with in the flow of 1745. In this case the bog shifted bodily, and the movement might, with more justice, than in most instances, be compared to that of a landslip. The late eruption of Knocknageeha was one of the largest on record, and is also characterised by the unusually large proportion of water present in the liberated material. Hence its rapid flow.

Summary of Previous Explanations of Bog-bursts.

In giving the following short review, we desire to acknowledge our indebtedness to Klinge's valuable paper alluded to below.

Leonard[1] remarks that "a great quantity of water collects in damp years on the bottom of the bog, which water held down by the turf seeks a subterranean outlet."

Bronn[2] points out the living peat bog may absorb from 50 to 90 per cent. of water, and so swell to double its volume : it is to this cause that the dome-like form is due. When the bog lies on an inclined plane, heavy rains will cause the bog to swell, and possibly burst.

Lesquereux[3] states that if peat bogs are deep, and lie higher than the neighbouring country, and if the drainage is not properly attended to, water will accumulate at the bottom of the bog. As the surface does not rise any higher, and water is no longer absorbed by the vegetation, the lower layers of the peat become softened and converted into a kind of soup. The crust of the bog bursts under the pressure of the contained fluid.

Senfft[4] repeats Bronn's view regarding excessive surface absorption, adding that, if a bog swollen by rain is situated on a slope, it

---

[1] Mineralogische Taschenbuch für das Jahr 1823, 3 Abt., p. 861.
[2] Handbuch einer Geschichte der Natur. Bd. ii., Th. ii., Stuttgart, p. 496, 1843.
[3] Untersuchungen ueber Torfmoore, p. 165, 1847, Anmerk.
[4] Die Humus-, Marsch-, Torf-, und Limonitbildungen, p. 102, 1862.

tends to bulge out like a bag down the slope, and finally bursts. He lays special stress upon the rapid bladder-like swelling that sometimes precedes an eruption.

Noeggerath[1] says, if the felt-like covering of extensive bogs, highly strained by water and gas, suddenly breaks, mighty streams of mud pour forth.

Kinahan[2] has attributed some bog-slides to shrinkage cracks, formed during drought, and enlarged by the subsequent entrance of water.

Klinge,[3] the latest investigator of these phenomena, propounds an entirely new theory, and expresses views on the constitution of peat bogs differing in some respects from those usually accepted. He labours to prove that the absorption of sub-aerial water, or the development of large quantities of gas, are insufficient to account for the bursting of bogs. He regards mountain bogs as of two different kinds, those which have grown in the uniform climate of the western coast of Europe, characterised by a continual increase in the degree of decomposition from their surface downwards, and those which have arisen under the influence of severe changes of climate ; the latter consist of alternating layers more or less highly decomposed. The different layers have different saturation limits for water, and these limits once attained never alter. There is no vertical movement of water through a bog. This view, the author asserts, stands in complete opposition to statements made by older writers as to the absorption by bogs of from 50 to 90 per cent. of their bulk of water. In support of his contention that peat bogs are impermeable, he appeals to pools on their surface, often 5 to 10 feet in depth, separated by peat-walls only 3 to 5 feet thick, and yet with water levels differing from each other by several feet. The dome-like form of mountain bogs he regards as inexplicable, unless a high capacity for water in conjunction with imperviousness be admitted for the peat. Excessive rainfall accumulates in pools on bogs, which are drained by surface channels. Pools only occur on bogs near the wet western coast of Europe. The author

---

[1] Der Torf, 1875, p. 12.

[2] Valleys in their relation to Fissures, Fractures, and Faults : London, 1875, p. 10.

[3] Ueber Moorausbrüche, Botanische Jahrbücher, Bd. xiv., 1892, p. 426.

makes an interesting observation on the dessicating effects of sphagnum on the air over mountain bogs. This is so great that on the leeward of these bogs, at least in Norway and Nova Zembla, an aero-xerophytic (dry air) flora occurs.

The immediate cause of an eruption of a bog is, according to Klinge, the violent irruption of water into the bog from below.

In discussing Klinge's views we may first point out that the mountain bogs of this country belong to his first class—those in which the decomposition of the vegetable matter increases from the surface downwards. The decomposed peat is heavier than water, and tends to accumulate at the bottom; the crust on which the growing plants are found is lighter than water, and floats on the top of the bog. It is between the crust and the lower layers that we should expect the most fluid portion of the bog to occur.

We cannot agree that the crust is impermeable; the fact that bogs can be drained is opposed to such a view; nor do the pools which Klinge instances afford conclusive proof in its favour; they may be explained by a difference in permeability of the surrounding peat, and that they are being drained of water, or have been supplied with it, it is possible, at different rates.

The subject is discussed in the Report of the Commissioners on Bogs, some of the surveyors taking the same view as Klinge. Thus Mr. Townsend[1] states that strata of turf of a firm and close texture, impervious to water, exist in every bog; and he is "decidedly of opinion that the springs under the bog do not penetrate upwards through this substance, but that the wetness of bogs is caused by the rain-water falling on the surface, and lodging in the small cracks and indentures"; the water slowly drains away by the natural descent of the surface. A similar opinion was held by Mr. Longfield, who says that "the vegetable matter of which the bogs in his district (River Brusna) are composed is *perfectly* retentive of water, so much so that the numerous duck-pools and lodgments of water in bogs are almost all upon different levels"; and he mentions "two considerable bodies of water at the distance of a few perches only from each other and yet differing $2\frac{1}{2}$ feet in level."[2] Mr. Edgeworth remarks of certain

[1] Second Report Commission on Bogs, Appendix No. 7, p. 154, 1811.
[2] *Ibid.*, p. 5.

bogs in the district of the Inny and Lough Ree that "some drains 6 to 7 feet wide, and as many deep, had been made from the centre of the bog to its outlet : these were about 20 perches asunder, and although they had been finished for twenty years, and were not choked up, the bog did not appear to have been affected by them."[1]

The Commissioners remark on this subject that the lakes on bogs are situated in hollows, and the material forming the banks of these is more solid than that of the general crust.[2]

We see no reason to doubt the correctness of the accepted view, which regards a peat bog as consisting of a fluid interior, more or less viscous, and an outer felted crust. The closing up of drains and canals, cut into bogs, is a familiar phenomenon which supports this view. It has been remarked by Sir R. Griffith, who states that "every kind of bog drain will in time become narrower at the top than when originally formed ; the drains made by the canal company . . . have now become considerably narrower at the top" ;[3] and by Mr. G. H. Kinahan, who informs us that on one occasion he opened a canal in the hard margin of a bog, 20 feet deep and 30 feet wide at the top ; this, twelve years later, was reduced to a depth of from 5 to 6 feet, and to about the same width. Mr. Kinahan predicts that in ten or fifteen years' time the site of the recent debacle will be scarcely visible ; the present depression in the bog will have become converted into a hollow from 10 to 15 feet below the level of the surrounding bog.

Although the felted envelope of a bog is close enough at its margins to afford support to the fluid interior, it is often broken by holes in the middle ; into these the soft, black fluid of the interior oozes up, as everyone who has traversed a wet bog is well aware. Through such openings rain-water may make its way, and join the liquid accumulation below the crust.

All mountain bogs present very similar features ; and the fact which appears most wonderful is not that they burst, but that they do not do so more frequently.

Evidently the crust, in its natural state, is, as a rule, equal to

---

[1] Second Report, Commission on Bogs, p. 6, 1811.   [2] *Ibid.*, p. 6.
[3] *Ibid.*, p. 9.

the task which the contained water puts upon it, and it is only when weakened by unusually deep cuttings that it gives away.

If this cause be considered sufficient, it might be thought unnecessary to discuss the question further, yet we think that the eruption of water from below, as Klinge suggests, though not as he postulates sudden and violent, may sometimes, perhaps frequently, have played a chief part; that, indeed, not a decrease in the support afforded by the crust, but an increase in the pressure of the contained fluid may have been the last in a train of causes which brought about the catastrophe. In the present instance the whole structure of the country (fig. 4) would lead the geologist to
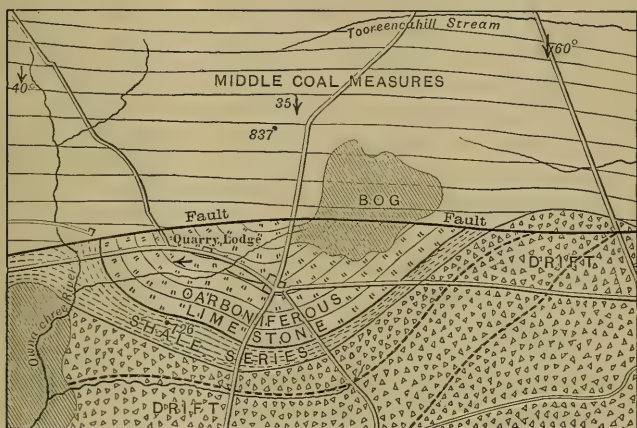
Fig. 4.

Geological Map, founded on that of the Geological Survey, showing the fault which underlies the sunken portion of the bog. Scale 1 inch to a mile.

suspect the existence of springs: the southward dip of the beds forming the rising land to the northward of the bog, would convey subterranean water towards it from a large catchment basin; the fault underlying the bog would serve as a conduit, through which this water would rise beneath it. The water draining away from such a spring would give rise to the wet line in the bog. The existence of such a spring would also afford an explanation of the origin of the bog; about the waters escaping from it, bog plants

would naturally spring up, and would thence spread outwards and upwards; but since their growth would commence near the spring, it is there that we should expect to find the bog attaining its greatest height above the level of the surrounding country.

That the water contained within many bogs is supplied by springs was fully recognised by careful observers as early as the beginning of the present century, as will appear from the following quotations:—" The summits . . . of bogs are generally the deepest and invariably the wettest parts . . . large lakes covering the surface. . . . The summits are composed of fluid peat. The fluid peat at the summit is of so soft a nature that boring irons descend 16 to 18 feet by their weight alone. Over the fluid peat is from 1 to 2 inches of water. In summer the bog dries, but the summit continues wet for 200 or 300 acres, and supplies streams. Springs are often met with in the deepest part of the bog, rushing up sometimes with much violence, and often strongly impregnated with sulphate of iron, carbonic acid, and earth. The water of almost all the springs in the bogs deposits oxide of iron on the beds of the streams in passing from the source through the bog. There is a very strong chalybeate spring issuing from the fissures of a limestone rock, whose beds are vertical, in the bottom of a cut-out bog near Newpark. . . . I have observed of a deep drain, made several years ago, to take away the water from a lake in the bog of Moanahinch, that it still continues to discharge a considerable quantity of water, although the lake has been drained. . . . This water issues from springs, which perhaps first formed the lake. There is also a constant discharge of water throughout the year from other lakes in the same bog near the summit, and consequently without any supply but from springs."[1] And the same writer concludes as follows:—" That the wetness of those bogs originates from springs within themselves, and that the principal springs must be at the summits."[2] Mr. Edgeworth also remarks, with reference to Ringowny bog, in the Inny valley, that it is "kept marshy by springs of its own, of which there

---

[1] Aher., Appendix No. 2, Third Report, Commission on Bogs, p. 65.
[2] *Ibid.*, p. 66.

are several. . . . These springs are not concealed, but filled to the brim by water issuing from the gravel beneath them."[1]

Mr. G. H. Kinahan has also clearly recognised the connexion which exists between the loughauns or pools on the surface of a bog and subterranean springs.[2] The existence of springs has been recognised in the peat bogs of other countries, as in Norway. Thus Stangeland speaks of small tarns which occur in certain bogs, mostly those which lie in narrow valleys with an uneven bottom. These he considers must be caused by subterranean springs. It is worth notice in passing, however, that this author assigns another origin to the swamps which occur on many large bogs; these he regards as a necessary stage in the development of a bog, which occurs when it is large enough to receive and retain a great quantity of water. This accumulates in a superficial pool, and when the wind agitates the water, the peat moss, which is very sensitive to wave-motion, cannot thrive at the bottom of the pool. In dry seasons the pool becomes a black muddy surface, and in wet it forms a clear layer of water.[3]

In view of the probability that much of the water discharged from the bog had its origin in springs, the occurrence of an earthquake about ten days before the disaster should not be overlooked. The earthquake was felt from Kew, in Surrey, to as far west probably as Miltown-Malbay, its epicentre seems to have been situated near Hereford; and we might fairly expect that the disturbance which produced it should have continued along the great structural features trending east-to-west, which extend from Wales through the south of Ireland. Any change in the distribution of material along the fault, that we have several times mentioned as passing beneath the scene of the late eruption, would be likely to affect the subterranean drainage.

The two views, one that looks for the cause of the outbreak in heavy rain, and the other which invokes the action of springs, and perhaps of earthquakes, are not mutually exclusive; both causes may have acted together, or sometimes one, and sometimes the

[1] Second Report, Commission on Bogs, Appendix 8, p. 192.

[2] *Op. cit.*, pp. 108–109.

[3] Torvmyrer of G. E. Strangeland, Norges Geologiske Undersägelse, Kristiania, 1892, p. 63.

other. Some outbursts, however, almost certainly owed their origin to the influx of subterranean water, *e.g.*, that of Randalstown (September 17th, 1835), when the bog swelled up till its convexity was 30 feet in height, and after sinking, was again raised in the course of a few days.

The question as to which of the two, in a given instance, is the correct explanation, is evidently not one of mere theoretical interest, for much will depend on our knowledge of the source of water issuing from bogs in devising plans for their drainage.

This was clearly recognised by the surveyors employed on the Commission on bogs, as is shown by the following :—

" To ascertain whether the wetness of these bogs originates solely from rain-water falling on the surface, or from springs in the interior of the bogs, or from both, is an inquiry of very great importance, and deserving serious consideration, as the system of drainage should be regulated thereby ; if, for instance, it was supposed to originate from rain-water only, shallow water surface drains would be sufficient, but should it be found to originate from springs rising up through the bog, a system of deep drains calculated to intercept and convey the water of those springs to a more convenient outlet should be adopted."[1]

Although a great work was accomplished by the Commission on Bogs at the beginning of the century, little has been done since ; a few organized attempts have been made from time to time to turn some of our peat bogs to better use, but the want of success which has generally attended them seems to have discouraged further effort, and thus a possible source of vast national wealth has been left to undeserved neglect.

On the Continent it is far otherwise ; there the investigation of peat bogs receives the attention that the importance of the subject demands. So great is the interest taken in the subject in Germany, that a society numbering more than 600 members exists there, having for its object the advancement of knowledge of peat culture, under which term more is comprised by German workers than might be supposed. This society publishes " Mittheilungen " fortnightly ; those for 1896 make a volume of 476 pages in royal

---

[1] Aher, Third Report, Commission on Bogs, Appendix iii., p. 60.

octavo. A similar society exists in Sweden: it was founded in 1885, and now numbers over 3300 members. It possesses experimental peat farms, where investigations are made on methods of cultivation; it employs a skilled agricultural engineer, who is occupied, travelling through the country, in giving information and advice to the peat farmers. A botanist is kept at work on the microscopical examination of peat, and a chemist to perform analyses. A "Tidskrift" is published bi-monthly; the collected numbers for 1896 include 304 pages of letterpress. By means of this journal, yearly meetings, discussions, lectures, and exhibitions, the Society is earnestly engaged in diffusing information on all subjects connected with peat industry throughout the kingdom.

There can be no doubt that in considering the agricultural question, the present Government has not overlooked the question of peat bogs; but we might take the opportunity to point out that a department, which has long been in existence—we allude to the Geological Survey of Ireland—has mapped the boundaries of all low-lying bogs in the country, though not of those which occur on higher ground. It would seem that an extension of the functions of this Survey, by which it could undertake a more thorough investigation into the structure and geologic history of peat bogs, would materially assist its usefulness.

EXPLANATION OF PLATES.

———

PLATE XVIII.

Fɪɢ. 1.—A portion of the subsided area of the bog, showing the torn and fissured surface.

Fɪɢ. 2.—The road to Killarney, where overflown by the boggy flood. Masses of peat are shown piled upon the road.

———

PLATE XIX.

Fɪɢ. 3.—Margin of the peaty deposit of the flow, where it lies on the fields, just beyond the Killarney road.

Fɪɢ. 4.—The limestone quarry, filled by the flood, up to the limit of the black band produced by a deposit of peat on the walls.

GEOLOGICAL MAP

OF

IRELAND

SHEWING DRIFT.

Prepared from
Published Sheets, thereon indicated
by figures.

BY

J. R. KILROE,

H. M. GEOLOGICAL SURVEY.

Scale of this Map. 27 Miles to One Inch

NOTE.—Drift areas, uncoloured.
Concealed rock boundaries, dotted lines.
Letters indicate rock formations according to Index.

FORMATIONS.

INDEX.
OF
Colours, &c

Formation		Symbol
Pliocene Clays		k.
Cretaceous Limestone, "Chalk"		h.
Trias and Lias. Grits, Shale & Limestone.		f g.
Carbon-iferous	Coalmeasures, Millstone Grit, and Yoredale. (Grits, Shales, &c.)	d³
	Limestone	d²
	Culp Sandstone and Lower Carboniferous Shale & Sandstone	d¹²
Old Red Sandstone	Sandstone Shale and Conglomerates	c
		b
Silurian and Cambrian (Grits and Shales)		a g
Metamorphic Rocks	Quartzite Mica-schist	u q
Acid Igneous Rocks (Granite, Felsite, &c)		G F
Basic " " (Basalt, Diorite, &c)		B D

Plate XVI.

Plate XVII.

fly Faunas.

Oriental ▨▨▨   Australian ▧▧▧

Map of the World; showing the approximate range of the Dragonfly Faunas.

| Neotropical | Sonoran | Holarctic | Ethiopian | Mascarene | Oriental | Australian |
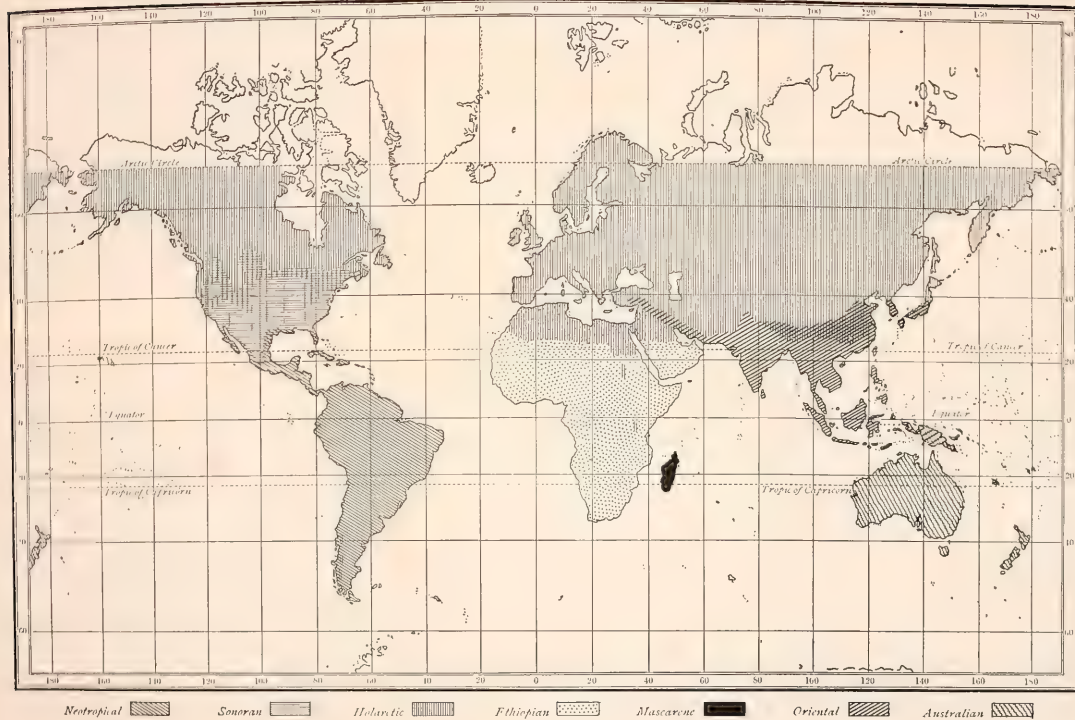
Fig. 1.

Fig. 2.

FIG. 3.

FIG. 4.

THE

SCIENTIFIC PROCEEDINGS

OF THE

ROYAL DUBLIN SOCIETY.

CONTENTS.

The Authors alone are responsible for all Opinions expressed in their Communications.

Price Eight Shillings and Sixpence.

CONTENTS—*continued.*

LVIII.

ON THE GEOLOGICAL INVESTIGATION OF SUBMARINE ROCKS. (PLATE XX.)

By J. JOLY, M.A., B.A.I., Sc.D., F.R.S., Hon. Sec. R.D.S.

PROFESSOR SOLLAS, in calling attention to the importance of investigating the various theoretical views put forward to account for the formation of coral reefs, has suggested obtaining observational evidence of the activity or inactivity of the coral-building polypes at considerable depths below the surface of the sea by actual descent of the observer in a suitable marine observatory.

Considerations as to other possible means of investigating this matter have given rise to the subject-matter of this Paper.

Not only in the particular case of the coral reef would geological science be enriched could we get into our hands samples of the rocks forming the floor of the ocean, but the attainment of this result, in general, would probably greatly enlarge our knowledge of the geological record so far as this may be revealed by examination of the surface-rocks of the Earth's crust. We have only to examine the charts of our coasts to appreciate this fact. At very considerable distances from our shores, up to distances of some 300 miles westward in the Atlantic, a rocky bottom is, in places, revealed by the soundings. Specimens of those rocks would be of great interest to the geologist. Are they volcanic, plutonic, or sedimentary? To add even a limited knowledge of the submerged to what is known of the emergent, suggests possibilities too many to discuss.

An apparatus which seeks to accomplish the object of bringing up samples of the flooring rock of the sea, where this is sufficiently free of surface-material, even from very great depths, is

described in this Paper. It is of the nature of a drill, electrically driven, which will, when lowered to the bottom of the sea, bore out a cylindrical portion of an uncovered rock, detach this from the parent rock, and retain a hold of the specimen till the apparatus is raised in safety to the surface. The nature of the rock can then be examined at leisure. In the case of the coral reef, its vitality could thus be investigated.

A great variety of contrivances, and on various scales of magnitude, can be devised for accomplishing the end in view, having all the essential character of an electrically driven drill. Doubtless the form described here admits of improvement. Practice would probably suggest many additions. I merely describe a form which, while enabling, it is hoped, the desired result to be attained in many cases, will be sufficient to test the feasibility of the apparatus at small expense.

Plate XX. shows, in part diagrammatically, a vertical section of the apparatus to a scale of one-fourth proposed trial dimensions. The rapidity, or the power of the drill, will of course depend upon what dimensions we confer upon the motor. The mass of the whole, as acting to confer immobility upon the apparatus while the drill is at work, also enters into consideration. In the trial form proposed, it is not intended to secure a high rate of working speed, the idea being that improvement in this direction is assured upon increased expenditure on the construction of the apparatus.

The drill D consists of a steel tube set with diamonds. The cutting edge is chisel-shaped, to secure a more rapid bite when the rock is first attacked, and also to facilitate the escape of detritus. The boring edge is about three-sixteenths of an inch wide in cross-section to allow for the housing of the cutting blades which sever, by a horizontal cut, the connection of the drilled-out plug with the rock. It must be remembered, in considering the rate of speed and the nature of the action of the drill, that there is complete lubrication of the cutting edge throughout, and that a high rate of speed is therefore allowable. Further, a cowl may be attached to the upper open end of the drill-tube so constructed as to direct a current of water downwards through the tube upon the rotation of the latter, thus washing all detritus out from the boring.

The armature and field magnets of the motor are indicated diagrammatically by the letters A and F. The drill-shaft, it will be seen, is continued as a uniform cylinder axially through the armature. In this it is free to move vertically ; but, owing to the restraint imposed by projections from the cylindrical shaft of the drill engaging in vertical slots in the interior of the armature (not shown), is turned with the rotation of this latter. The upper extremity of the drill-shaft is furnished with a screw-fan which, reacting against the inertia of the water when the drill is being rotated, produces the requisite pressure of the latter against the rocky bottom. The amount of this pressure is of course adjustable, depending upon the dimensions and pitch of the blades of the fan as well as on the rate of speed at which this is driven. Experiment must decide the best conditions of velocity and pressure for any particular dimension of apparatus.

When being lowered to the bottom, the spiral spring, shown in section as coiled around the drill-shaft just beneath the fan, retains the drill in its highest or most raised position. The fan is covered in with a covering of thin sheet-iron, freely perforated, or wire-netting, and elsewhere it will be seen that the entire form of the apparatus is such as to ensure it against being entangled in sea-weeds.

When the slackening of the lowering wire indicates that the apparatus has attained the bottom, the current is switched on to the motor. An insulated twin-wire connects this with the surface. The observer is provided with voltmeter and ampèremeter.

It is evident that for each voltage read there corresponds a particular position of the drill in its vertical path. This is due to the fact that, for slow rates of speed, the fan is working only against the reaction of the spring. A few experiments made in shallow water will show at what level the drill will stand when such-and-such a voltage is indicated. I will suppose now that the first lowering of the drill has not been upon a suitable spot; may be it has descended on sand, may be just over a small crevice. The observation of the voltage will reveal this at once. We find in this case that, as we urge the drill downwards, the voltmeter reveals that the armature is still running away without meeting any appreciable resistance, or that only an inappreciable

amount of work is being done. The readings of the voltmeter are, in fact, those we observed when we ran the drill in shallow water with the cutting edge unemployed. Finding this, we raise the apparatus a little, and shift our ground, and so make trials till we find that the drill becomes engaged after we lower the drill but a little way. The readings in this case change character. The voltage and current now not only tell us that the drill is at work, but we may tell immediately at what rate it is doing work. The presence of the spiral spring thus confers a power of *feeling its way* upon the apparatus.

To guard against the tendency of the whole machine to turn with the drill, considerable mass is conferred, in addition to the heavy nature of the machinery, by the presence of a heavy base of lead beneath the motor, and sharp claw-like feet. But in conferring the best form upon these feet, experiment will probably be needed. In the case of the coral reef, standing at a high slope, a much wider base would be required.

I may observe here that it is probably unadvisable to seek to render any part of the apparatus watertight. The internal space around the motor may, if desired, be filled with a thin oil, such as paraffin, before submergence.

It will be perceived that, in the diagram, the drill is depicted in its lowest position ; the ring carrying the fan-blades has come into meeting with the collar encircling the spiral spring. It would save loss due to friction if this collar, which stops the downward descent of the drill, was a prolongation of the tubular shaft containing the drill, and hence turning with it. Similarly the spring might well rotate with the outer shaft. In this design, the vertical range of the drill is only something about an inch. It is intended for both hard and soft rocks. A greater range would be desirable in the case of the coral reef. In the diagram, the vertical cut is supposed to be completed. The drill has attained the lowest point in its vertical range.

The mechanism by which the dissevering of the bored-out plug is effected remains to be described. Near the lower extremity of the drill, just above the cutting edges, two horizontal slots are carried through the thickness of the metal. These house two curved saws, armed with diamonds. These are pivoted

on strong vertical spindles, contained in vertical slots carried up in the walls of the drill for a few inches. Above, the spindles carry each a semi-cylindrical fan which may fold down upon the drill-shaft, or swing outwards so as to extend as vanes from either side of the drill-shaft, as seen in the plan of the drill-saws. These vanes are not rigidly attached to the saw-spindles, but only engage upon them when opened into such a position as shown in the full lines on the plan. Any further opening of the vanes must be accompanied by corresponding angular rotation of the saw-spindles. Finally, after a certain range of rotation, the vanes are hindered from further deflection by stops affixed upon them at the back, which then bear against the wall of the drill-shaft. These details of construction are omitted.

Looking at the sectional elevation, it is seen that the vanes, when the drill-shaft is in its lowest position, just escape the base-plate above them. When the drill occupies a higher position, the vanes are, in fact, folded down upon the drill-shaft, and contained within the hollow armature of the motor. They are sprung a little upon their seats, so that upon the descent of the whirling drill to its lowest position, as in the drawing, the vanes are released, spring out a little, immediately catch the water, and are then pressed open till they engage upon the saw-spindles. After this, they can only open wider by rotating these spindles, and, in doing so, urge the cutting edges of the saws inwards upon the column of rock still left standing within the drill. The high rate of rotation of the drill ensures that the pressure so brought to bear upon the cutting edges of the saws is very considerable, and it is steadily maintained till the vanes attain their extreme deflection under the pressure of the water. In this position, the saws have met within the rock, and occupy the dotted position of the plan. The space occupied by the rotating vanes is shut in below by a removable perforated plate, and a bodily swirling of the water is checked by fixed vanes projecting from the sides.

When this horizontal cut is finally effected, the measuring instruments in circuit at once reveal the fact to those above. The motor runs away, and the counter e. m. f. generated indicates on the voltmeter that the apparatus may be raised. An approxi-

mately vertical pull now withdraws the drill, retaining within it the excavated rock. It is evident that the saws will retain the final dotted position shown in the plan. When, in fact, the current is stopped, the spring pulling the drill upwards maintains the vanes pressed against the base-plate above them and so fixes them in their position of extreme deflection. In this position the saws meet across the opening of the drill-shaft, and the loss of the specimen is impossible.

In place of cutting-saws, a cutting wire or chain may be used. This wire may be lodged in a horizontal groove within the drill at its lower extremity. When the drill has attained its lowest position, the release of the fans effects the rotation of a loose collar which carries the fans, rotates on the drill-shaft, and is attached to one extremity of the cutting wire by means of a rigid extension extending downwards in the inside of the drill-shaft. The rotation of the collar is thus accompanied by the gradual pulling of the cutting wire into the diametral position. When this position is attained the horizontal cut is complete. This form has the advantage of requiring a drill of less thickness in the walls than the first form, but experiment alone will show how far it may be relied upon in the case of a hard rock.

In many cases the rock beneath the sea is probably covered with but a shallow thickness of mud or sand. In such cases it would be possible to modify the apparatus so as to enable it to bore through this covering. Experience will probably show that the electrical measurements and observation of the duration of drilling will, at any rate, after a single trial of the rock, enable a a sufficient estimate to be made, by those at the surface, of the depth to which the drill has penetrated. An electrical release may then be employed to stop the vertical cut and liberate the vanes, and so commence the horizontal cut or simply reversion of the direction of rotation of the drill might be used to stop the vertical cut, and at the same time call the vanes and saws into operation. The mechanism would be of the simplest kind.

But trial of the form first described, upon ground where bare rock is assured, will at once be a test of all such modifications so far as their essential features are concerned.

LIX.

SHORT ACCOUNT OF AN EXPERIMENT TO DETERMINE THE EXACT POSITION IN A FOCUS TUBE FROM WHICH THE X-RAYS ARE EMITTED. By THE VERY REV. GERALD MOLLOY, D.D., D.Sc.

I took a deal board, 7 inches long by 5 broad, and three-quarters of an inch thick, into which I drove fifteen long slender nails, making three rows, with five nails in each row. The nails had small circular heads, and when fixed in position stood about one inch above the level of the board. This board I now attached to the back of a fluorescent screen E, by means of two elastic bands, as shown in figure 1 (p. 516). The fluorescent screen was mounted on a stand A, the foot of which fitted tightly into a wooden socket F, at the end of an arm B, capable of moving round a centre C. The centre of motion C was simply a screw driven into the lecture table, and allowing the arm to move freely round in a circle.

The Focus Tube was now carefully adjusted so as to make the plane of the platinum plate vertical, with its centre in the horizontal line of the middle nail in the deal board, and in the vertical line passing through the centre of motion C ; and the fluorescent screen was made perpendicular to the arm B, so that in all positions of the arm, the screen and the deal board attached to it should be tangential to the circle described.

When these arrangements were completed, I placed the wooden arm B in such a position that the plane of the fluorescent screen made an angle of about 45° with the plane of the platinum plate in the Focus Tube. The room having been then darkened, the current was turned on, and the shadows of the nails appeared on

the screen, as shown in figure 2. The shadow of the central nail appeared as a black spot a little larger than the head of the nail, and the shadows of the other nails went out symmetrically from the centre : those above went upwards, those below downwards ; those on the right went to the right, those on the left went to the left. The interpretation of these facts was very simple and clear :
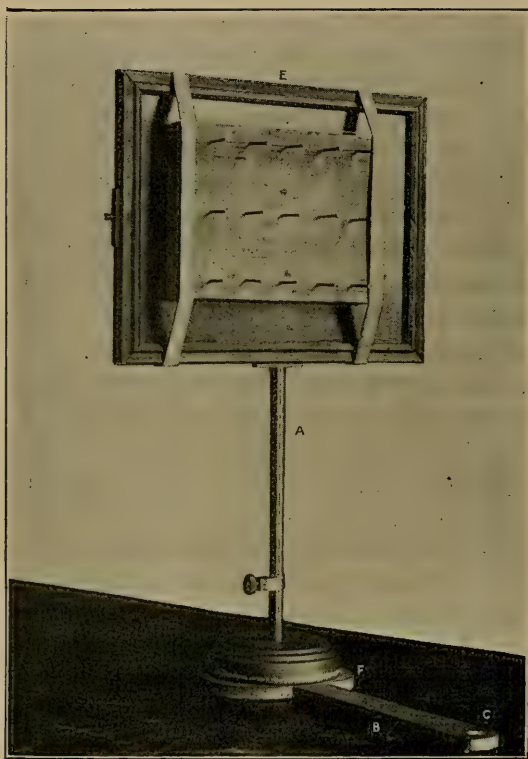
FIGURE 1.

the area of radiation was small, as shown by the sharpness of the shadows, and the centre of that area was in the line of the central nail produced.

The question now was, what would happen to the shadows if I moved the arm B round the centre C, thus making the board of nails revolve in a circle to which it would always remain

tangential. This was a question which it was easy to answer, with the arrangements before me. When I moved the arm, the shadows remained absolutely fixed, and the figure on the screen remained, in all positions of the screen, exactly what it had been in the first position I had tried. It followed, that the centre of the area of radiation was in the line of the central nail produced, for all positions of the board; therefore it was at the point where all these lines would meet, that is, at or about the centre of the platinum plate.[1]

FIGURE 2.

Having thus determined the position from which the X-Rays were emitted, I next proceeded to determine the size of the area of radiation, by means of a pin-hole image. I placed a metal plate, with a small round hole pierced in it, in a vertical position, facing the platinum plate, and about six inches distant from it; and I placed the fluorescent screen at the same distance from the metal plate, on the other side. When the current was then turned on, as before, and the room darkened, I got a luminous spot on the screen, which, under the geometrical conditions of the

---

[1] Perhaps I should explain that the black patch close to the second nail from the right hand corner above, in the figure, is due to the presence of a piece of an old nail, which unknown to me was imbedded in the deal board.

experiment, must have been an image of the area of radiation, and equal to it in size. This image I found to be irregularly circular in form, hazy and ill-defined round the edge, and about a quarter of an inch in diameter.

In connexion with this result, it is interesting to note a fact which must, I think, have fallen under the observation of most persons who have worked at the X-Rays. There is always one small spot on the platinum plate which first begins to glow; and it is not difficult so to regulate the current as to keep this spot glowing with a red heat, while the rest of the plate remains dark. This is evidently the area of fiercest bombardment, and it must be situated at or near the focus of the Cathode stream. It is irregularly circular in shape, ill-defined in its outline, and about a quarter of an inch in diameter. I think, therefore, we may infer that this glowing spot is, in fact, the area from which the X-Rays are emitted.

LX.

A NEW METHOD OF CONFERRING DISTINGUISHING CHARACTERISTIC APPEARANCE UPON ILLUMINATED BUOYS AND BEACONS FOR HARBOURS, ESTUARIES, AND RIVERS. By JOHN R. WIGHAM, M.R.I.A., Member of the Council of the Royal Dublin Society.

Most of the Papers which I have brought before this Society on the subject of Lighthouse Illuminants have had reference to improvements in the illuminating power of the great lighthouses on our sea-coasts. Most of these improvements have been adopted by the Lighthouse authorities of this country, the apparatus which I have described to this Society having been fixed at their lighthouses; for example, at the famous Eddystone, the Tuskar, Tory Island, Mew Island, Galley Head, Hook Tower, Haisbro', Mine Head, Wicklow Head, Bull Rock, Howth (Bailey), Rockabill, Slyne Head, and other great leading and landfall lights.

This Paper has no reference to these great lights, but to what may be termed minor lights. It has been found, of recent years, that lights fixed on the beacons and buoys which mark the rocks and shoals of our navigable rivers and estuaries, to show the safe channels by which these dangers may be avoided, if not as important to the mariner as leading and landfall lighthouses, yet possess for him great value, by enabling him to deal with these dangers at close quarters, when he has passed the greater lights and has reached their shoreward side, where they are of little further use to him. Hence it is, that increasing attention is being given to the improving and perfecting of these smaller lights,

placed on beacons and buoys, to guide him under such circumstances.

I had the honour of reading a Paper before this Society on the 22nd of January last* on a method which I had devised for using common petroleum as the illuminant for beacons and buoys, by which, at exceedingly low cost, a continuous light can be maintained day and night for weeks or months without the necessity for the attendance of a light-keeper. I described in that Paper the method by which that form of light was, by means of a revolving wick, kept burning for that length of time, without attendance. These lights have been permanently adopted in Belfast Lough, and other places, and have been found successful.

Lighthouse authorities have determined that, for distinctive purposes, two kinds of buoys shall be used in marking rivers, and the fairway of harbours and estuaries, viz. conical buoys and can buoys; the former to mark the starboard side in entering the river or harbour, and the latter the port side. This distinction is, of course, useful in the daytime when the buoys are perfectly visible; but to establish a similar characteristic distinction at night, it is advisable to differentiate the lights on the buoys or beacons, and it has been suggested that bright, white lights should be used on the starboard side, and red on the port side.

Some harbour authorities having called upon me to produce an occulting light which might be suitably used as marking one side of a river in contradistinction to fixed lights which might be used for marking the other, I devised the lamp here described. It will be seen by the simple plan of its construction that we can not only have occulting lights on buoys and beacons, but that we can superadd the further distinction of colour, say, besides light and dark alternately, we can have white and red, or red and dark, or green and dark, or amber and dark, or any other variety that may be fixed upon.

In this case the arrangement by means of rotating wicks, by which the light is maintained for a month together without attendance, is the same as that described in my previous Paper.

---

* Scient. Proc., Royal Dublin Society, vol. viii., Part v., p. 377.

The occultations are occasioned by causing the lamp itself to be the motive power; the heat of the lamp acting upon the mica blades of a small fan which is caused continuously to revolve by the upward current of air resulting from the combustion of the lamp. Slight arms of steel which support the two screens of opaque, or coloured, or translucent material, such as talc, are so arranged that they balance each other and keep up, as they pass in front of the flame, a continual occultation and re-exhibition of the light. If it be desired to have a quicker repetition of the occultation than can be produced by two shades, three or four can be substituted for two, and thus the flashes will be rendered more frequent.

I exhibited on a former occasion, for the illustration of one of my Papers, a pulsating light, consisting of eight first order annular lenses, by which it was demonstrated that by the plan of rotation which I had devised the powerful light transmitted by these lenses was caused to remain in the eye as a continuous light, even when the lenses were continually revolving, and would otherwise cause intervals of darkness. I refer to this here merely because the same device is employed in this case. The effect of the continuous light which I have described was produced by the method by which the lenses were caused to revolve. They were mounted on a steel pivot, working on a piece of agate, causing so little friction that the great group of lenses (weighing about one ton) could be made to revolve by an exceedingly slight pressure, and hence great rapidity of revolution was practicable.

The same contrivance is adopted in the case of the little lamp here described. The pivot system is adopted also in this case, and so little friction is created that an exceedingly feeble upward current of air is sufficient to put the apparatus into motion. The simplicity of this device is its chief recommendation, for clockwork complications or other mechanical appliances would be quite unsuitable for the exposed positions in which such lights are placed. The balancing of the fan is so exact that, although the light may be fixed to a buoy which is subjected to the motion of the sea, the rotation is maintained with practical uniformity. Of course, if the lamp be used in a beacon which is perfectly steady, the rotation of the flashes is absolutely periodic; but even in the

case of buoys where the lamp, owing to the motion of the sea, is unsteady, the flashes, for all practical purposes, are sufficiently regular and distinctive.

———

Note.—The Paper was illustrated by a working model showing the movement to which buoys are subjected by the action of the sea, and the gimbal arrangement by which that motion is neutralised and the flame of the lamp kept steady, an occulting apparatus (showing white and red light alternately) being fixed in connexion with the gimbal arrangement.

LXI.

NOTES ON A PAPER RECENTLY PUBLISHED IN THE
ASTROPHYSICAL JOURNAL,[1] by PROFESSOR E. HALE,
of the Yerkes Observatory, Chicago, on " THE COMPARATIVE
VALUES OF REFRACTING AND REFLECTING TELE-
SCOPES FOR ASTROPHYSICAL OBSERVATIONS." By
SIR HOWARD GRUBB, F.R.S., Vice-President, R. D. S.

THE very first memoir in the first volume of the Transactions
of the Royal Dublin Society (New Series, 1877), was a Paper
by the author on " Great Telescopes of the Future." That Paper
was written at a somewhat critical period in the history of large
telescopes, and was intended to draw attention to several advan-
tages which reflecting telescopes possessed, more particularly for
spectroscopic and certain lines of physical work, which advantages,
in the opinion of the author, rendered it probable that the great
telescope of the future would be of the reflecting and not of the
refracting type.

Glancing back for a moment over the past history of tele-
scopes, it will be remembered that the development of the reflect-
ing telescope got its first impetus from the failure of Sir Isaac
Newton to achromatize telescopic objectives. Even after "Dolland"
had perfected his great invention of the achromatic objective, re-
flectors were in considerable favour on account of the difficulty of
procuring perfect pieces of optical glass, but as this difficulty
decreased the reflecting telescope, then always made with metallic
mirrors, gradually lost ground on account of the difficulty of
renewing the optical surface when tarnished.

---

[1] Vol. 5, No. 2, Feb. 1897.

About the sixties, the invention of Foucalt of using silvered glass mirrors, instead of metallic, gave the reflector a new lease of life, until it was found that the silver film was very perishable in the neighbourhood of towns. Moreover, the advance made in the manufacture of optical glass, has rendered it possible to obtain discs of a size almost comparable with the large reflecting telescopes.

It was about this time that the author published the Paper referred to, thinking that the deserved popularity of the refractor had caused the many strong points of the reflector to be overlooked.

The strongest advocates of the refractor have, undoubtedly, been in the New World, where most of the great modern refractors have been built and installed, and it is therefore somewhat surprising, but at the same time gratifying to find from the Paper referred to in the title of this Paper, that American astronomers are becoming quite alive to the many strong points of the reflector, and that a Paper from the pen of one so eminent in his profession as Professor Hale should contain such a remarkable confirmation of the views expressed in the author's Paper referred to above, and published twenty years ago.

Professor Hale, in his Paper, treats the subject in a far more exhaustive and complete manner than that which the author was able to do twenty years ago. He points out in the first place the actual necessity that exists for the building of telescopes larger than we have as yet attempted, if we desire to solve some of the great astronomical problems of the day ; he says :—

" But those who wish to materially reduce the probable error of wave length determinations of lines in stellar spectra, either for the purpose of increasing the accuracy of line of sight measurements or to render possible such detailed studies of certain lines as are now made in the solar spectrum, must be content to wait for the construction of telescopes much larger than the great instruments of the present day."

He then points out the particular classes of observations which the reflector is suitable for, and shows that that perfection of definition which the imperfection of our atmosphere renders impossible is not necessary in these particular observations.

Referring to the author's Paper of 1877, he corroborates what is there said about the distinctive advantages of each form, and then enters into a most exhaustive and valuable examination of the relative light collecting powers of refractors and reflectors when used for visual work and when used for photographic work.

An elaborate table is given of the various results of his analyses, and also a diagram which represents the same in a graphical form, which latter is here reproduced (see p. 526).

An examination of this diagram will show that whereas the refractor is a more powerful light collector for visual rays up to about four feet in diameter, the reflector then, and for sizes over this aperture, becomes the more powerful in consequence of the fact that owing to the increased thickness of the glass the absorption of light is greater. The difference, however, is never very great for visual rays. In the case of photographic rays, however, the absorption in the case of the refractor is so great that at one metre diameter the reflector becomes 50 per cent. more powerful; at 2 metres it is 100 per cent. more powerful than a refractor of equal size; while at a little over 3 metres aperture the absorption increases at such a rate *that no more light is collected by increasing the aperture.*

The conclusions, therefore, which Professor Hale comes to are as follows. He says: " As regards the future development of telescopes in the direction of increased light-grasping power, the reflector promises far greater gains than the refractor, especially for spectroscopic work in the so-called photographic region. Indeed it appears from an inspection of the curves in the diagram that an increase in the aperture of an objective beyond about 350 centimetres would be attended by no gain in the intensity of the photographic image. In the case of reflectors, on the contrary, the light grasping power will continue indefinitely to gain with the aperture."

The author desires to take this opportunity of thanking Professor Hale for his courteous reference to the Paper above referred to in the Transactions of the Royal Dublin Society.

DIAGRAM OF PLATE REPRESENTING THE VARIOUS RESULTS OF PROFESSOR E. HALE'S GRAPHICAL ANALYSES.
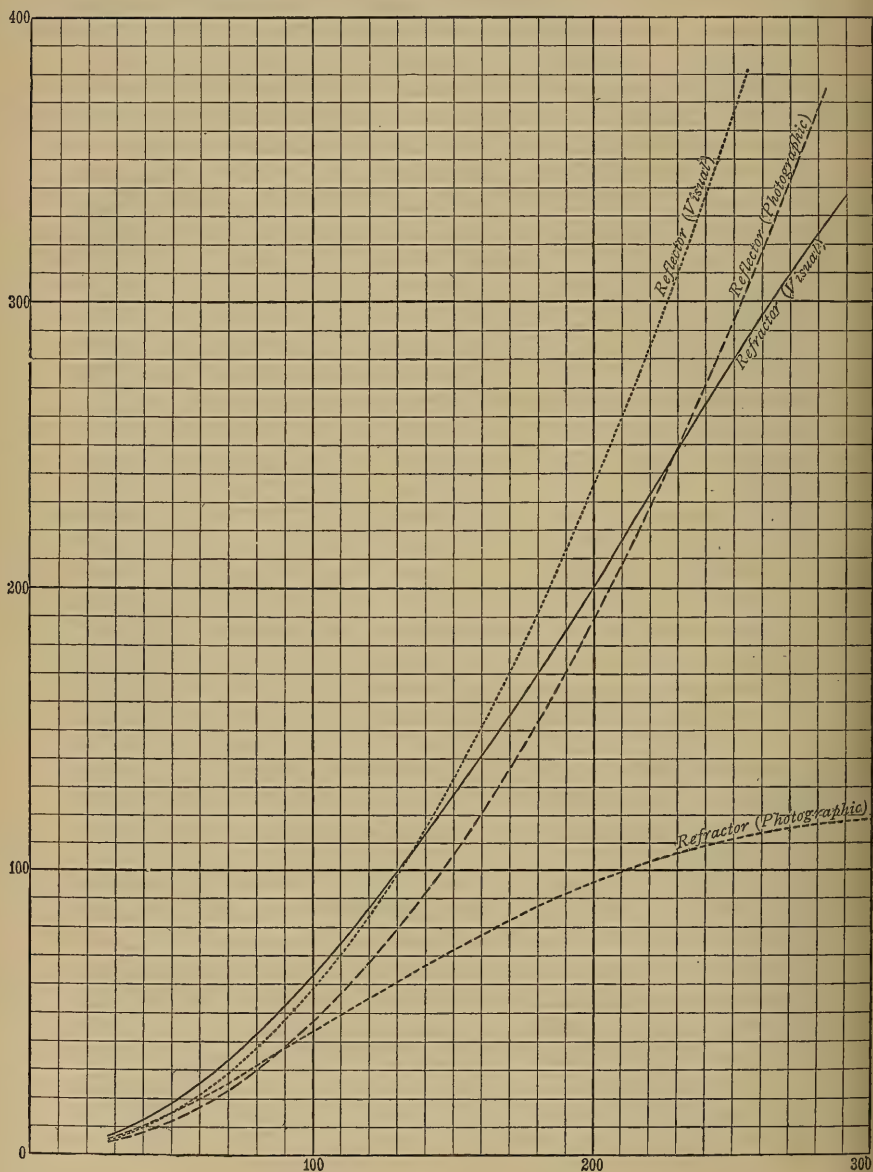
LXII.

A MECHANICAL CAUSE OF HOMOGENEITY OF STRUCTURE AND SYMMETRY GEOMETRICALLY INVESTIGATED; WITH SPECIAL APPLICATION TO CRYSTALS AND TO CHEMICAL COMBINATION. By WILLIAM BARLOW.

From the early days of crystallographic study, attempts have from time to time been made to find some clue to the nature of the ultimate structure of crystals by means of artificial devices which imitate as closely as possible the various kinds of symmetry displayed by these bodies; these attempts have mainly consisted in packing together spheres, ellipsoids, and other regular bodies in a symmetrical manner, the methods employed being generally such that the packing is the closest possible, and the bodies packed together being all alike.[1]

In the meantime, however, evidence has been accumulating, notably in connexion with stereo-chemical investigations, that a regular repetition in space which portrays the homogeneity of structure of crystals should be that of groups composed of two or more individuals rather than that of single bodies as generally hitherto represented, and further that the bodies forming a group need not be similar. Thus, if we adopt the simile used by Lord Kelvin, and compare the homogeneous structure of a crystal to a regiment of soldiers in battle array,[2] we shall in many cases take a troop of cavalry rather than one of infantry for the comparison,

---

[1] Comp. "Molecular Constitution of Matter," by Sir William Thomson, in *Proc. Roy. Soc. of Edinburgh*, vol. xvi. pp. 712–715.

[2] "The Molecular Tactics of a Crystal." Second Robert Boyle Lecture, 1893, p. 26.

and distinguish a man from his horse, while at the same time generally, in a sense, regarding them as one.[1]

Perhaps the simplest conceivable kind of closest-packing which gives this diversity in unity of the elements of the structure, is that of a large number of spheres of two, three, or more different sizes; and, as will be seen in the following pages, the variety of types of symmetry obtainable in this way, when a great number of different ratios between the sizes of the spheres are taken, is comparable to the variety presented by crystals.

When further we find that numerous other facts concerning crystals are paralleled by the properties of closest-packed symmetrical assemblages composed of balls of different sizes, we may be tempted to conclude that, in cases where closest-packing of balls all of the *same* size does not suffice, the real state of things is pictured in outline by the simple kind of closest-packing just referred to, and if this be so we shall conceive the " spheres of influence " of the atomic properties or movements, whatever these may be, to be *strictly spherical* around certain centres, so that polarity in a crystal is traceable to the *disposition* and not to the *forms* of the spheres of influence of its ultimate parts.

This is, perhaps, not unlikely, but it is proper to remark that the existence of the parallelism alluded to by no means establishes the propriety of using *spherical* balls in all cases. For every crystal not of the cubic system can be conceived to be deformed in such a way as not to alter the type of symmetry of its parts or properties, and since corresponding deformation of an assemblage of balls representing its symmetry would alter the spheres to spheroids or ellipsoids, we see that while the latter forms are not necessarily indispensable for the portrayal of the lower types of symmetry, they will always do as well as spheres so far as the geometry is concerned.

An objection to the simple kind of closest-packing in question

---

[1] If the definition of homogeneity of structure suggested by the author (see Mineralogical Magazine, vol. xi., p. 120) is adopted, there are types of homogeneous arrangement whose representation would require the units of the troop to be *not* all similarly orientated, and some which would involve the military inconvenience of each man being related similarly to more than one horse, and each horse related similarly to more than one man.

is that the distance between the centres of two spheres of given sizes which touch one another is the same throughout an assemblage of this kind *whether the line joining them has in all places the same relation to the general symmetry or not.*[1] This arbitrary feature is obviated if, instead of rigid spheres placed against one another without pressure, we employ elastic deformable balls differing in material as well as in size, and subject the closest-packed assemblage to some uniform compression which flattens the spheres at the places of contact. An assemblage thus constituted can be regarded as equivalent to a flock of mutually-repellent particles occupying the places of the ball-centres, and which is in equilibrium;[2] provided that repulsion subsists only between near particles whose interaction is represented by the effect on one another of balls which touch. Equality of lines whose situations are unlike is now avoided, and at the same time the polarity is still that of the *disposition* and not of the *forms* of the ultimate parts. The type of symmetry will not be materially affected by the modification referred to.

In what follows we shall mostly content ourselves with the use of the undeformable balls, believing that the changes occasioned by using the elastic ones instead, would in all cases be quite symmetrical and immaterial so far as type of symmetry is concerned. The employment of spheroids or ellipsoids in place of spheres appears, as just remarked, to be unnecessary.

For the purpose of imitating two of the principal universal properties of molecular matter, the balls employed will be (1) regarded as suffering contraction or expansion under change of conditions, those of one size, composed of one material, changing at a different

---

[1] Comp. Note 2, p. 550.

[2] Some simple equilibrium arrangements for mutually-repellent particles of two kinds have been suggested by Lord Kelvin, the particles being under a constraint in addition to exhibiting repulsion. (See "Molecular Constitution of Matter," *loc. cit.,* pp. 699, 700.)

It is conceivable that the spheres of influence around centres of force of one or more kinds found recurring throughout some uniform mass of matter *appropriate to themselves distinct portions of space as large as possible* as a consequence of the interaction of the molecular movements or properties. And if this is the case, we appear to be furnished with a system of mutually-repellent spheres of influence whose stable equilibrium will be reached when the arrangement is a closest-packed one.

rate from those of another material, and (2) it is postulated that ball can be attached to ball by a practically inextensible tie reaching from centre to centre through the place of contact, so that when tied in this way, the centres of two balls cannot get further and further apart under change of conditions, and thus the balls have, so to speak, to inter-penetrate between tied centres if they expand. The last-named postulate is intended to imitate to some extent the different kinds of aggregation of the ultimate parts of matter.[1]

The simple materials thus provided,[2] the different balls of different materials,[3] with their power of expansion and contraction under change of conditions, and their faculty of attachment to form groups, are now to be put together in various ways *which fulfil the condition of closest-packing*, this principle being the foundation stone of the present inquiry. The arrangements obtained will be compared with various phenomena of crystallization,[4] chemical isomerism, chemical combination, and diffusion.

The work may be regarded as supplementary to the geometrical work on the nature of homogeneity which the author has already published, by which he has shown that every homogeneous structure, whatever its nature, displays one or other of the thirty-two kinds of crystal symmetry.[5]

The various effects producible will be found to range themselves under seven heads, viz. :—

I.—Symmetrical arranging of parts converting a fortuitous assemblage into a homogeneous assemblage and subsequent preservation of the homogeneity by the application of the ties, an effect

---

[1] Where the linking thus defined is sufficiently complete to prevent any *free* movement of small parts of the assemblage with respect to one another, the assemblage will in the sequel, be said to be solid.

[2] For a more precise statement of the concepts employed, see Appendix.

[3] Sometimes it will be convenient to think of an artificial system as consisting of mutually-repellent particles instead of balls of different kinds (see above).

[4] A reference to some of the conclusions as to crystals reached in this memoir was made by the author at the Cardiff Meeting of the British Association, 1891. Diagrams showing some of the kinds of symmetry dealt with were published in *Nature*, 1883, vol. 29, pp. 186 and 205.

[5] See Mineralogical Magazine, vol. xi., p. 119.

which, since crystals are homogeneous structures,[1] resembles that arranging of the ultimate parts of a body, and stereotyping of the arrangement, which constitute crystallization.

II.—Partial dissolution in a symmetrical manner of the ties which attach the parts of a linked assemblage, and subsequent partial destruction of the homogeneity, so that the assemblage breaks up into groups in each of which the parts are symmetrically placed with respect to one another, while the arrangement of the groups has become irregular, the groups thus resembling the theoretical molecules of stereo-chemistry.

III.—Symmetrical intercalation of homogeneous assemblages whose forms are identical or appropriately related, comprising formation of twin assemblages, including under this head the symmetrical fitting together of enantiomorphous assemblages as well as that of identical assemblages; the formation of isomorphous assemblages and their intermixture, and the symmetrical interlocking of unlike assemblages. Comparison to crystal-twinning, isomorphism, isogonism, and crystalloid structure, also to some kinds of diffusion.

IV.—Interlacing of different kinds of groups or individuals, converting a fortuitous assemblage into an assemblage which approximates to homogeneity, but does not reach it, because the arrangements for closest-packing are not homogeneous ones.

V.—Combination of two or more homogenous or approximately homogeneous assemblages to form a single homogeneous or approximately homogeneous assemblage; an effect which, (*a*) in its most perfect form finds a parallel in that highly symmetrical intermixture of the combining atoms or complexes which must, it is evident, accompany or precede a chemical synthesis,[2] and which

---

[1] Homogeneous, that is to say, according to the definition given by the writer in his memoir: "Ueber die geometrischen Eigenschaften homogener starrer Structuren," &c. Zeitschrift für Krystallographie, &c., 23, p. 1.

Comp. Mineralogical Mag., vol. xi., p. 120; or Zeitschr. für Kryst. 27, p. 450.

[2] This effect is very closely related to that defined in I.; indeed these two effects may be said to overlap. Under head I., however, the salient point before us is the symmetry of arrangement which succeeds a more or less chaotic state, while under head V. it is the uniform intermingling of different kinds of particles or elements *in precise proportions* which claims our attention. The latter condition is a result of the former which may survive the symmetry to which it owes its origin; it may exist continuously while the symmetry productive of it is intermittent and fluctuating.

(*b*), when the assemblage produced is only imperfectly homogeneous, may be paralleled by some phenomena of diffusion.

VI.—Breaking up of an assemblage into two or more distinct assemblages ; an effect resembling the disentangling of the separated atoms or complexes which commonly follows a *chemical decomposition*, and also resembling the crystallizing out of a constituent from a liquid or partially-liquid mixture.

VII.—Exchange of the constituents of two or more assemblages so as to constitute fresh assemblages ; an effect which finds a parallel in the re-arrangement or re-distribution which is one of the features of *double chemical decomposition*.

The object kept in view throughout will be, not so much to ascertain with precision what particular relations between the parts lead to the formation of particular arrangements, as to show broadly that relations are conceivable which will lead to the production of the variety of results above enumerated as a direct physical consequence of closest-packing carried out under the conditions indicated.

As to the connexion between actual phenomena and the properties of the artificial systems obtained in the way here described, I would say that so large a number of resemblances can hardly be regarded as *all of them* mere coincidences, although some of them may be, and that we are therefore justified in concluding that some mechanical causes akin to those here traced are actually operating in nature.

I.—Symmetrical arranging of parts, converting a fortuitous assemblage into a homogenous assemblage, and subsequent preservation of the homogeneity by the application of the ties ; an effect which, since crystals are homogeneous structures, resembles that arranging of the ultimate parts of a body and stereotyping of the arrangement which constitute crystallization.

(**A.**) *Formation of homogeneous assemblages when the balls, or mutually-repellent centres, are all of one kind.*

The simplest case is that presented when the balls are all similar and independent of one another.

When this is so, it is not difficult to show that the relative

disposition of the ball centres which gives closest-packing, is one in which each ball is in contact with twelve others. For if a number of equal spheres be stacked together, twelve is the greatest number of them which can be in contact with any given sphere, and a closest-packed arrangement is realized by the sphere-centres of a stack consisting of plane layers triangularly arranged in which each sphere is in contact with six others, and the succeeding layers are so disposed that every sphere is also in contact with three others of the layer above, and three of the layer below it.[1]

But since there are two different positions in which a second plane layer can be deposited to fulfil this condition, it is evident that twelve contacts for each sphere can be attained in a variety
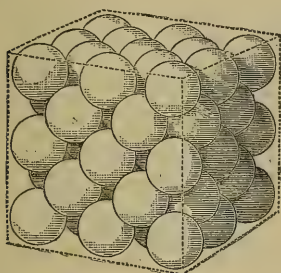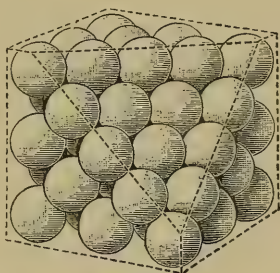
Fig. 1.   Fig. 2.

---

[1] Even this simplest of all cases of closest-packing has not, so far as I am aware, ever been exhaustively treated, or its various possibilities expressed algebraically. (See Lord Kelvin on the arrangements here referred to in "Molecular Constitution of Matter," by Sir William Thomson, *Proc.* Royal Soc. of Edinburgh, vol. xvi., p. 712, note * and p. 715.) As those who have employed the conception of closest-packing of *similar* bodies have contented themselves with a treatment which is comparatively rudimentary and not exhaustive, considerable difficulty must be looked for in any attempt to deal exhaustively with the closest-packing of bodies *of more than one kind*. I am, however, not without hope that, when the importance of the subject is realized, experts in analytical methods may be found who will indicate precise ways of arriving at some of the closest-packed arrangements described in the succeeding pages. I anticipate that should some of these arrangements prove not to be the closest-packed possible, the arrangements which supplant them will in all, or nearly all, cases be found to be homogeneous, and will therefore serve the purposes of the argument equally well.

I may say that my general principle for getting closest-packing of the spheres is to produce a maximum number of contacts, so as to diminish, as far as possible, the amount of interstitial space.

of different ways. There are two, and two only, which give homogeneity of structure,[1] viz.:—

(*a*.) An arrangement in which the sphere centres occupy the centres of a symmetrically selected half of the cubes of a cubic partitioning of space. This is shown in figs. 1 and 2,[2] and is of the type marked $8a_2$ in the lists of types of homogeneous structure given by the writer,[3] and has the generic symmetry of class 28 in Sohncke's list of Krystallklassen.[4] The centres form a singular point-system,[5] each of them being the intersection of tetragonal, trigonal, and digonal axes and of the planes of symmetry.

(*b*.) An arrangement in which the spheres of alternate layers are directly over one another, the projection of the system being shown in fig. 3. The sphere centres then exemplify that particular case of Sohncke's system 52, which is obtained when the generating point lies at the point of intersection of one of the trigonal and one of the digonal axes of the system, and the distance separating successive layers of the system is such that each

Fig. 3.

point is equidistant from twelve nearest points. Such a system possesses planes of symmetry in which the points lie, and also centres of inversion, and is a singular point-system. The type of homogeneous structure to which it belongs is that marked $24a_2$,[6] the " doppelte Systeme," of which are of the kind numbered 87*a*

---
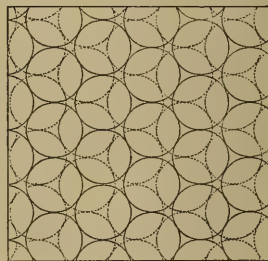
[1] See note 1, p. 531.

[2] Fig. 2 has one corner of a cubic group truncated to show the triangular close-packed arrangement of the spheres in planes perpendicular to the cube diagonals.

[3] Zeitschr. für Kryst. 23, p. 44. The references given here, and in subsequent examples to the lists contained in the author's former works on homogeneous structures, and to Sohncke's list of the thirty-two classes of crystal symmetry are supplied for the convenience of those who desire to examine particular cases closely; it is scarcely necessary for the purposes of the general argument that the reader should look them up.

[4] *Ibid.*, 20, p. 466.

[5] *Ibid.*, 23, p. 60.

[6] Zeitschr. für Kryst. 23, p. 45. Compare Sohncke, Entwickelung einer Theorie der Krystallstruktur, p. 115; also *Nature*, Dec. 20, 1883, vol. xxix., p. 186.

in Fedorow's list;[1] it has the generic symmetry of class 9 in Sohncke's list of Krystallklassen.[2]

As a and b are just as closely packed, one as the other, it would seem, at first sight, that in every case where the centres are of a single kind, one of these arrangements is as available as the other. But this can hardly be the case, for it is conceivable that the initial disposition of the centres may by some means, perhaps fortuitously, be nearer to the one arrangement than to the other in some given case; and if this is so, the assemblage will pass more easily to the arrangement to which it thus already approximates, and on reaching it can experience no disposition to adopt the other. *And further, a fortuitous arrangement is, in some respects, nearer to form (a) than to form (b).* For, in a, the planes most thickly set with ball centres have four different directions, viz., those perpendicular to the cube diagonals, while in b they have but one such plane direction. And if we suppose that, starting with a fortuitous arrangement, the first step towards closest-packing is the production of a large number of aggregations in which closest-packing prevails, but which are *variously orientated*, it is obvious that the passage to a *continuous* closest-packed arrangement which absorbs all these, will partly consist in reducing the number of the different orientations of the groups, and that, as the movements requisite to reduce them to four will be less, on the whole, than would be requisite to bring them to a single common orientation, the cubic arrangement marked a will generally be easier to reach than the hexagonal one marked b.[3]

If, as in the last case, the balls are all similar, *but are aggregated to form a number of similar groups in which each ball is similarly linked to the remaining balls of its group,* the conditions obviously become much more complex, and it is easily seen that the closest-packed arrangement will but rarely be of the type just named.[4]

---

[1] Zeitschr. für Kryst., 24, p. 236.   [2] *Ibid.*, 20, p. 460.

[3] The argument is perhaps easier to follow if we think of the balls as shaken close together in a bag.

[4] If the reader desires to study the *simpler* cases of arrangement before he addresses himself to the more complex, he should pass on at once to the cases in which the balls are of two kinds. (See p. 546).

If, for example, the similar centres are similarly linked together two and two, closest-packing gives different arrangements according to the distance apart of the two centres of a pair as compared with the distances separating nearest centres in different pairs when equilibrium is reached.   The consideration of a few particular cases renders this clear.

Thus suppose :—

(*a*) That the distance between the two centres of a pair is small[1] compared with the distances between those of the nearest pairs when equilibrium is reached, so that the balls of the pair interpenetrate one another very considerably.

When this is so the arrangement which gives closest-packing will still, very approximately, be that of the simpler case given above, except that now the points midway between the two centres in each group or pair, instead of the centres themselves, will have the arrangement of the sphere centres in the assemblage depicting a closest-packed arrangement of unlinked spheres of a single kind.

The assemblage will not, however, be homogeneous unless the relative orientation of the pairs conforms to the definition of homogeneousness above referred to.   The only relative orientation which conforms to this definition, and also has the symmetry of the regular form, is that in which the centres all lie on trigonal axes situated as in type 1 of my list[2] (System 58 of Sohncke), the line joining the two centres of a pair coinciding everywhere with such an axis.   If the pairs have this relative orientation, a homogeneous structure is presented which has the axes and coincidence-movements (Deckbewegungen) of type 1, and possesses in addition centres of symmetry (of inversion) lying at the cube centres of the space partitioning which I have employed to generate this system.[3] It is, therefore, a structure of the type numbered 1a_{1} in my list,[4] and displays the generic symmetry of class 31 in Sohncke's list of Krystallklassen.[5]   The two centres of a pair are equidistant from the centre of the cube in which they lie, and they are found on the single trigonal axis of this cube ; their positions are not identically

---

[1] Not infinitesimal.   [2] Zeitschr. für Kryst., 23, p. 6.
[3] *Ibid.*, 23, p. 7.   [4] *Ibid.*, p. 44.   [5] *Ibid.*, 20, p. 467.

alike, but enantiomorphously related. As they lie on axes they are singular points.[1]

If in the case under consideration a homogeneous arrangement is produced, it is probably this.[2]

Suppose next :—

(b) That the distance between the two centres of a pair is relatively large, so as very nearly but not quite to allow the balls to take the arrangement prevailing when they are all independent.[3]

In this case an arrangement approximating closely to the compact arrangement taken up by the balls when independent will
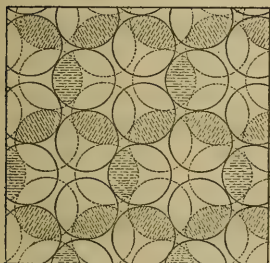
Fig. 4.

obviously be produced; it cannot, however, be a homogeneous one belonging to the cubic system, because it is not possible to connect the points of the closest-packed cubic system above described, two and two in such a way that the arrangement of the ties shall comply with the definition of homogeneousness and belong to the regular system. In some instances of this kind probably an arrangement of the balls

according to the system 21 of Sohncke with centres of inversion, *i.e.*, of type 49a$_1$, in my list[4] will result, the generic symmetry being that of class 12 in Sohncke's list. The projection of a stack of spheres whose centres would have such an arrangement is shown in fig. 4, the balls being so placed as *very nearly* to have the alternative closest-packed homogeneous arrangement

---

[1] *Ibid.*, 23, p. 60. Comp. Min. Mag., vol. xi., p. 132.

[2] Other symmetrical orientations which are consistent with homogeneousness will be found to give a lower degree of symmetry and would probably not give such close packing.

[3] A comparison of the specific weights of different bodies composed of the same atoms in the same proportions, but whose molecules are of different degrees of complexity, rather favours the conclusion that, *in the solid and liquid states*, if as the stereochemists suppose, the atoms have definite situations, the distances separating the nearest atoms of *different* molecules of a substance are frequently not very much greater than the distances separating the nearest atoms of the same molecule.

[4] Zeitschr. für Kryst., 23, pp. 30 and 46.

shown by fig. 3.[1] In such a grouping, the centres linked are in different layers, and the positions of the two ball centres of the pairs are identical;[2] they are singular points in planes of symmetry. The two projections of alternate layers are shown in the figure. Layers between which the linking obtains will be rather closer together than other succeeding layers.[3] The relative position of two linked balls is indicated by connecting with dotted lines the projections of the spheres whose centres pair together.

Finally suppose—

(*c*) That the distance between two centres of a pair is slightly but not much less than in the last case.

It is then conceivable that the closest-packing will be reached in a homogeneous arrangement belonging to the regular system whose axes are those of type 5 in my list[4] (system 62 of Sohncke), and which is obtained by placing a point on a trigonal axis very near either to one of the cube centres, or to one of the cube angles of the space-partitioning employed to generate this system,[5] and generating a point-system by carrying out the coincidence-movements (Deck-bewegungen) of the same system. The ball centres to be regarded as linked together will be those lying nearest to one another on the same trigonal axis. The structure obtained will be of the type numbered 5 in my list, and display the generic symmetry of class 29 in Sohncke's list.[6] The positions of the centres are all identical, and they are singular points lying on trigonal axes.

Where, on stable equilibrium being reached, the distance between two centres forming a pair bears some other relation to the distances between the pairs than those prevailing in the three cases referred to, the closest-packed arrangement, towards which the assemblage continually approximates, will be in some cases homogeneous, in other cases probably unhomogeneous. To be homogeneous it must, as we know, possess the coincidence-movements of some one of the 65 systems of Sohncke, and will generally be a specialized system of very high symmetry.[7]

---

[1] See page 534.   [2] *i.e.*, not enantiomorphous.
[3] If the layers were all equidistant, the symmetry would, ignoring the linking, belong to one of the hexagonal types.
[4] Zeischr. für Kryst., 23, pp. 6 and 12. [5] *Ibid.*, 23, pp. 7 and 12. [6] *Ibid.*, 20, p. 466.
[7] See " Ueber die geometrischen Eigenschaften &c.'' Zeitschr. für Kryst., 23, p. 1.

Take next a case in which the ball centres, while all of one kind, are similarly linked to one another to form groups of three. Manifestly for each of the three centres of a group to be similarly placed with respect to the remaining centres of the same group, they must lie at the three angles of an equilateral triangle.

Suppose—

(a) That the distances between the three centres linked together to form a group are small as compared with the distances between the nearest centres in different groups when equilibrium is reached.

As in the corresponding case of groups containing two balls, very close packing will be attained if the arrangement of the groups is that of the sphere centres in figs. 1 and 2, but this would not appear in general to be the closest-packing possible if we take the shape of the groups into consideration, *i.e.*, unless the distance between the centres of a group is so small as to make the shape of the group quite inoperative. It would seem that the closest-packing possible is attained when the disposition of the groups approximates to the one referred to on p. 534 (and see fig. 3), and the orientation of the groups is such that the arrangement of the ball centres is that of a system 52 of Sohncke,[1] whose generating point lies on one of the digonal axes which intersects trigonal axes near to one of the latter, and on a line of intersection of planes of symmetry. The structure presented is of the type marked $24a_2$ in my list ;[2] and the generic system displayed by such a system is the holohedral symmetry of class 9 in Sohncke's list of Krystall-klassen.[3] The nature of the arrangement is shown in fig. 5, in which each group is seen to consist of three interpenetrating spheres which are in contact with the spheres of adjoining groups. The
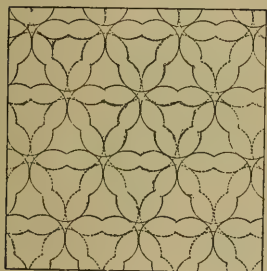
Fig. 5.

---

[1] See "Entwickelung &c.", p. 115. Compare Zeitschr. für Kryst., 23, pp. 23 and 25.

[2] See Zeitschr. für Kryst., 23, p. 45. The "doppeltes System" is No. 87a of Fedorow, Zeitschr. für Kryst., 24, ·viii., Taf. vi.

[3] Zeitschr. für Kryst., 20, p. 460.

projections of alternate layers are identical, so that two projections of succeeding layers suffice. The positions of the centres are all identical; they are singular points, and the digonal axes on which they lie are lines of intersection of those planes of symmetry which intersect trigonal and hexagonal axes.

Suppose next—

(β.) That the distances between the three ball centres forming a group are almost as great as the distances between the nearest centres in different groups when equilibrium is reached, so as very nearly to permit of the centres taking the arrangement of the sphere centres in figs. 1 & 2.

If the distances referred to differ only infinitesimally, we shall get an unhomogeneous arrangement very closely resembling in structure the closest-packed arrangement referred to, but lacking its definite polarity. If they are not infinitesimal it would appear that the conditions may be such as to give the closest-packing in an arrangement depicted in fig. 6, in which the three centres grouped around a hexagonal axis and lying in the same transverse layer are rather nearer together than to centres in other groups; as before the spheres interpenetrate in

Fig. 6.

threes. The system has the axes of system 52 of Sohncke (Type 24 in my list) with centres of inversion on the hexagonal axes and situated midway between the layers of points. Its structure is therefore of the type marked $24a_1$ in my list,[1] and has the generic symmetry of class 9 in Sohncke's list.[2] The positions of the centres are all identical; they are singular points lying on those of the digonal axes which intersect nearest hexagonal axes and also on lines of intersection of planes of symmetry.
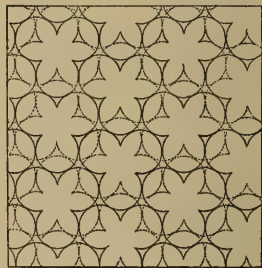
Take next a case in which the centres, while all of one kind, are similarly linked to one another to form groups of four.

---

[1] Zeitschr. f. Kryst., 23, p. 45. The "doppeltes System" is No. 88a of Fedorow (see Zeitschr. f. Kryst., 24, viii., Taf. vi.).

[2] Zeitschr. f. Kryst., 20, p. 460.

Several different kinds of grouping of four ball centres are possible consistently with this;[1] let us take the most symmetrical case, that in which the centres lie at the angular points of a regular tetrahedron.

Suppose—

(A.) That the distance between two centres of a group is small as compared with the distances between nearest centres in different groups.

As in the above cases in which a relation of this kind obtains, close-packing will be attained when the arrangement of the groups is like that of the sphere centres in figs. 1 and 2, and an arrangement approximating to this would give the closest-packing possible in cases where the distance separating centres of the same group is relatively very small indeed.

We see, however, that when, having this arrangement, the groups are orientated in such a way that the assemblage shall be a homogeneous structure belonging to the cubic system (*i.e.*, when the ball-centres lie upon trigonal axes) closest-packing is not attained; and therefore we conclude that in cases where the groups approximate to the arrangement referred to, the orientation is less regular than this, and the assemblage in consequence either unhomogeneous or of a lower degree of symmetry than the cubic.

If the arrangement is homogeneous, but has some lower symmetry than the cubic, the four centres of a group will not all bear the same relation to the structure. For example, if the symmetry is trigonal, we shall find not more than three of each group occupying similar positions, and if three are similarly related the fourth will lie on some trigonal axis.

Suppose next—

(B.) That the ball centres of the same tetrahedral group are further apart than in the case of A, but still much closer together than centres in different groups.

It would appear that cases now present themselves in which closest-packing is reached when the arrangement of the groups is that of the centres and angles taken together of the cubes in a

---

close-packed stack of equal cubes (that of a kubisches centrirtes Raumgitter), and the arrangement of the ball centres is that of a system 56 of Sohncke (Type 10 in my list), whose generating point lies on a trigonal axis near to, but not at, a cube centre.[1] Such a structure is of the type marked $10b_1$ in my list.[2] The generic symmetry displayed is tetrahedral hemihedrism, being that of class 30 in Sohncke's list.[3]

Suppose finally—

(C.) That the distance between two of the ball centres forming a tetrahedral group is almost as great as the distance separating the nearest centres in different groups.

The arrangement of the centres can now approximate very closely to that of the sphere centres of figs. 1 and 2. This is accomplished if the centre points of the groups form a cubic space-lattice, and the arrangement of the centres is that of a system 54 of Sohncke (type 7 in my list) whose generating point lies on a trigonal axis at a distance rather less than $d/4$ from a cube centre where d is the diameter of a cube of the space-partitioning which I have employed to generate this system. (If the distance were exactly $d/4$ the particles would have the closest-packed arrangement shown in figs. 1 and 2). The structure obtained is of the type numbered $7b_1$ in my list.[4] The generic symmetry, as in the last case, is tetrahedral hemihedrism, being that of Sohncke's class 30. There is, however, another arrangement of the tetrahedral groups of balls which gives equally close-packing with that just described. For a closest-packed cubic assemblage of spheres can be partitioned into tetrahedral groups in two different ways, *i.e.*, (*a*) one of the form just described in which the system, after partitioning, presents the type of symmetry No. $7b_1$, and (*b*) one in which each triplet of spheres forming a face of a tetrahedral group is fitted into a triplet of an adjoining tetrahedral group. The arrangement of the ball centres, when the groups are placed in this way, is that of a system 63 of Sohncke whose generating point lies on a trigonal axis at a distance rather less than $d/4$ from a

---

[1] "Entwickelung &c.", p. 157.   Comp. Zeitschr. f. Kryst., 23, p. 20.

[2] Zeitschr. f. Kryst., 23, p. 52.

[3] *Ibid.*, 20, p. 467.   [4] Zeitschr. f. Kryst., 23, p. 52.

cube centre or a cube angle, where d is the diameter of a cube of one of the two space partitionings employed in this system. (As in the previous case, if the distance were exactly $d/4$, the balls would have the closest-packed arrangement shown in figs. 1 and 2). The structure is now of the type numbered $9a_1$ in my list; the generic symmetry is the holohedral cubic; one half of the groups have their orientation opposite to that of the other half. The centre points of the groups lie, one set at half the cube centres of a cubic partitioning of space, the other set, which are oppositely orientated, at half the cube angles.

Groups composed of four similar similarly-placed balls arranged in some other way, *e. g.*, at the angles of a square, do not appear to be capable of very close-packing in a homogeneous manner when taken alone.

Take next a case in which the centres, while all of one kind, are similarly linked to one another to form groups of six.

Several different kinds of grouping of six centres are possible consistently with this;[1] let us take the simplest case, that in which they lie at the angular points of a regular octahedron.

Suppose—

(*aa.*) That the distances between the six ball centres linked together to form a group are small as compared with the distances between the nearest centres in different groups.

As in the case of groups of four similar centres, if the distances between the centres of the same group are relatively so small that the shape of the groups does not affect their relative arrangement, we shall get closest-packing in an unhomogeneous arrangement in which the relative situations of the centre points of the groups approximates to that of the sphere-centres of figs. 1 and 2.

Suppose—

(*bb.*) That the distances between the six ball centres forming a group are larger than in case *aa*, so that the form of the groups affects their arrangement.

Closest-packing will probably not now be attained in any homogeneous arrangement belonging to the cubic system; for, if the groups, appropriately oriented, be arranged with their centre

points to form either (1) a regular octahedral space-lattice, or (2) a cubic space-lattice, or (3) a cubic centred space-lattice,[1] the groups do not fit very closely together ; and these are the only three ways in which the ball-centres can be arranged so as all to occupy similar positions in the structure and to have cubic symmetry.[2]   Closest-packing would appear, however, to be attained in trigonal symmetry if the particles have the arrangement of a system which has the axes of type 49 in my list[3] (system 21 of Sohncke), and possesses centres of inversion lying at the intersection of trigonal and digonal axes, and the generating point be so situated in a plane containing nearest trigonal axes of the same kind that groups of six points are traced from it which form the angles of regular octahedra.   The structure is then of the type marked 49a$_1$ in my list.[4]   Fig. 6 will represent an arrangement of this nature, but the spheres will now interpenetrate in sixes, not in threes as in the previous case represented by this figure ; and the layers will not now all be equidistant, the distance between consecutive layers, each of which contains half the centres of the same groups, being less than that separating layers not thus related.   The symmetry displayed by such a system is scalenohedral hemihedrism, being that of Sohncke's class 12. If the distance separating the nearest centres in the same group becomes equal to the distance between nearest centres of different groups measured both in transverse planes of particles and also between the nearest particles of succeeding transverse planes, the arrangement becomes that of the very close-packed system referred to in page 534 and fig. 3.

We might pursue the investigation for cases of centres all of one kind linked to one another to form groups of more than six, but greater complication would then be encountered, because a greater number than six cannot be *similarly* placed with respect

---

[1] *i. e.*, (1) To form the centres of regular rhombic dodecahedra fitted together to fill space ; (2) to form the centres of cubes thus fitted together ; or (3) to form the centres and solid angles of such cubes, in other words to form the centres of cubo-octahedra thus fitted together.

[2] It seems unlikely that closer packing will be attained in any *homogeneous* arrangement of the particles in which they have not this similarity of position.

[3] Zeitschr. f. Kryst., 23, pp. 30 and 31.   Comp. Sohncke's Entwickelung, &c., p. 129.

[4] Zeitschr. f. Kryst., 23, p. 46.

to one another without producing a hollowness of the grouping, *i.e.*, the distance between the opposite centres of a group is then far greater than that separating nearest centres ; and hollowness of the grouping seems inconsistent with close-packing, so that it would seem that the centres, where more than six go to form a single group, must occupy positions with respect to the structure which are not identical with one another. When this is the case our task is similar to the one before us when we come to deal with cases of balls of more than one kind.

Enough has been said to show that, in the case of similar ball centres linked together in various ways, compact packing and homogeneousness of arrangement commonly go together, and we may regard the following proposition as established.

Closest-packing produces, under the given conditions, a great variety of homogeneous arrangements of balls of a single size, when these balls are fitted together to form symmetrical groups consisting of two, three, four, or six balls, and the balls which form a group interpenetrate. The nature of the arrangement is in each case determined by the relation which subsists between the distance apart of adjacent centres of the same group and the distance between the nearest centres of different groups.

The strict parallel as to general symmetry obtaining between the various homogeneous closest-packed arrangements of centres of one kind, some of which have just been traced, and the various crystal forms of the elements is obvious, the linking together of two or more of the centres to form a group being paralleled by the supposed linking together of two or more similar atoms to form a molecule.[1]

---

[1] It has sometimes been suggested that when atoms, whether of the same or different kinds, combine to form a molecule, the individuality of the atoms is lost, much in the same way that the individuality of a number of superposed movements of any kind is lost, and not separately discernible in the resultant movement.

The objection to this view is that, in the case of a chemical combination, we can always, by analysis, recover the same identical combining atoms from the combination, while in the case of combined movements the identity of the component movements is completely lost, so that we can no more say that the resultant movement contains the movements whose combination produced it, than that it contains any other of the infinite number of conceivable groups of movements which would have this same resultant. And this objection is supported by the evidence we have that the presence in a number

(B.) *Formation of homogeneous assemblages when the balls, or mutually repellent centres, are of two kinds.*

We now come to the cases of homogeneous arrangement brought about by closest-packing in which the balls are of two kinds only, and in some of which they are not linked together to form groups of any kind, while in others they are so linked.

In these and other cases in which more than one kind of ball is present, and provided the centres are unlinked, the nature of the arrangement produced will depend on the relative sizes of the balls of different kinds.[1]

For the sake of simplicity, let us first suppose that the ball centres are all confined to the same plane, but free to move in this plane.

If they were all alike and independent, they would evidently pack closest in the triangular arrangement, in which each centre is equidistant from six nearest centres, and they would display a less compact packing in the quadrilateral arrangement, in which each centre is equidistant from four nearest centres.
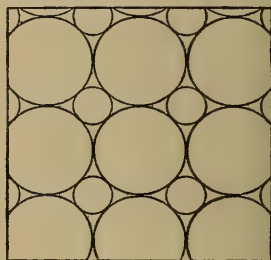
Fig. 7.

But when two kinds of balls, one larger than the other, are present, the triangular arrangement referred to may not give close-packing at all, and the sizes may be so proportioned as to give closest-packing in the quadrilateral arrangement depicted in fig. 7; this packing being somewhat closer than would be

---

of different compounds of a common constituent is very often the occasion of their possessing allied properties.

It should be remembered, in connexion with the resemblance that has just been pointed out, that some, or indeed all, of the so-called elements may prove in the end to be compounds. Where this is the case the remarks made later respecting compounds will apply instead of what is said here as to the elements.

[1] If elastic balls are used and the closest-packed assemblage is compressed (see p. 529), the arrangement will also, in nearly all cases, be influenced by the repulsions found subsisting between the different ball centres, these repulsions, at least such of them as have any modifying effect on the form of the assemblage, having to form a system in statical equilibrium.

attained by massing the two sizes separately in the triangular arrangement.

Let us now pass to the consideration of cases of balls of two kinds not confined to the same plane, and all independent of one another.

Suppose that the relation between the sizes of the two kinds is such that, when closest-packing is attained in a combination of the two, the centres of the large balls are found at the centres of a symmetrically selected half of the cubes of a cubic partitioning of space, *i. e.*, having the arrangement which would be the closest-packed possible if they were present alone[1]—in other words, that the smaller balls are small enough to go into the interstices between the larger ones when the latter have the closest-packed ar-

Fig. 8.

rangement referred to. It is then evident that the smaller balls are *inoperative* ones—that they have no share in the production of the general symmetry, but merely lie loosely between the balls whose interaction determines it, and which therefore may be designated *operative*.
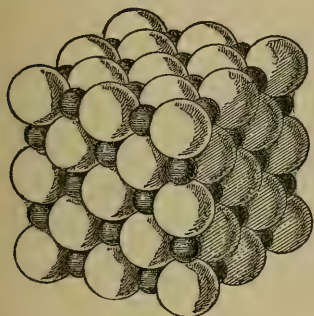
The larger of the interstices are equal in number to the closest-packed spheres; and if, in such an assemblage of spheres, the smaller-sized spheres are too large for the smaller interstices, while small enough for the larger, they will occupy the latter only.

In an assemblage of mutually-repellent particles of two kinds corresponding to this,[2] the relative positions of the particles exercising the lesser repulsions will be given by the centres of spheres just large enough to fit into the large interstices, the arrangement produced being that of the sphere-centres in fig. 8. In such an arrangement, the centres of one kind occupy the centres of half the cubes of a system of cubes into which space is divided, and those of the other kind the centres of the remaining half, each half system consisting of cubes in contact at their edges only. The

---

[1] That of the sphere-centres in figs. 1 and 2.　　　[2] See page 529.

structure is therefore of the type marked $6a_1$ in my list.[1]   Each kind of centre forms a singular point system,[2] centres of both kinds lying at points of intersection of tetragonal, trigonal, and digonal axes, and also in planes of symmetry.   The generic symmetry is the holohedral cubic, being that of class 28 in Sohncke's list.[3]

The use of spheres somewhat smaller than those which would just fit into the larger interstices would still leave the arrangement referred to the closest-packed possible, so long as they are not small enough for more than one to go into one of these interstices.   Corresponding to this we have the fact that the arrangement described is an equilibrium one for particles of two kinds, if when thus arranged the mutual repulsion between the particles of different kinds is either equal to or *less than* the repulsion between the particles of the same kind which have the closest-packed arrangement of figs. 1 and 2 ; provided the repulsion between the particles which correspond to the smaller spheres, and also that between these particles and particles of the other kind are considerable enough to prevent more than one particle from occupying any of the larger interstices, and any particles at all from occupying the smaller ones.

If spheres of two sizes are used, and the same arrangement of the larger spheres prevails, but the smaller spheres are small enough to go into the *smaller* interstices between the larger ones, closest-packing will be attained in some arrangement which is homogeneous so far as the disposition of the larger spheres is concerned if the arrangement of the smaller ones be neglected, but unhomogeneous if the smaller ones are taken into account, unless indeed the relative magnitude of the two kinds is such that the larger interstices are packed fullest when a number of the smaller spheres are arranged in each of them in a manner consistent with the homogeneity of the structure formed.[4]

In these and in all other cases of assemblages consisting of more than one kind of ball, it is manifest that unless the different kinds are present in the numerical proportions in which they enter into the particular combination which gives closest-packing of

---

[1] Zeitschr. für Kryst., 23, p. 44.   [2] *Ibid.*, p. 60.

[3] *Ibid.*, 20, p. 466.   [4] See note 1, p. 531.

them all, there will, when equilibrium is reached, be an excess containing one kind of ball less than is found in this combination, and that closest-packing applied to this excess will cause the balls composing it to take up the relative positions in which they occupy the least space possible.[1] We see, therefore, that the numerical proportions in which different kinds of balls are present will determine how far uniformity of arrangement shall extend throughout the entire assemblage. Where there are but two kinds of balls, as in the cases referred to above, the combination ultimately produced will exhaust the stock of one kind, and the kind which is present in excess will be arranged just as the sphere-centres are arranged in the closest-packed system above referred to.[2]

To proceed to other cases of equilibrium of two kinds of balls.

Another case of holohedral cubic symmetry.
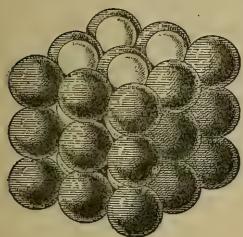
Fig. 9.

The two sizes may be so related that the disposition of the centres when the most stable equilibrium is reached is that of the centres of spheres of two sizes, where those of one size occupy the centres of all the cubes of a cubic partitioning of space, those of the other all the cube angles (fig. 9). In this case all the balls will be operative.[3] The type of homogeneous structure to which such an assemblage belongs is that numbered $7a_1$ in my list.[4] Each kind of centre forms a singular point system,[5] centres of

---

[1] As to the steps by which this ideally-perfect condition of most stable equilibrium will conceivably be reached in the case of an assemblage of mutually-repellent particles of two different kinds, patches of such a symmetrical combination as gives closest-packing will probably first appear at all places where the different kinds are in juxtaposition, then the two kinds will interpenetrate each other, and the patches of the compound assemblage formed will extend and combine till an arrangement is reached in which all of one kind of particle is in combination with the needful proportion of the other in a continuous mass as symmetrically arranged as possible. The remainder of the assemblage will consist entirely of the kind of particle which is present in excess arranged in one of the closest-packed forms for the uncombined state, probably in that depicted in figs. 1 and 2. There will, of course, be some irregularity and continual fluctuation at all boundaries. It is needless to add that, if change of state takes place before the ideally-perfect condition is reached, the process described will be only partially carried out. [2] See figs. 1 and 2.

[3] See p. 547. [4] Zeitschr. für Kryst., 23, p. 44. [5] *Ibid.*, p. 60.

both kinds lying at points of intersection of tetragonal, trigonal, and digonal axes, and also of the planes of symmetry. The two kinds are present in the same numerical proportions. The generic symmetry is holohedral, being that of class 28 in Sohncke's list.

A case of tetrahedral hemihedrism of the cubic system.

If the radii of two sets of spheres are very nearly in the proportion requisite for the assemblage in which the larger spheres have the closest-packed arrangement of figs. 1 and 2 and the smaller just fit into the larger interstices between them,[1] but the smaller are just too large to allow of the larger spheres being in contact, a different arrangement gives closest-packing of the spheres. This arrangement is obtained if the larger spheres, which will be not quite in contact when arranged as in the closest-packed arrangement referred to, approach one another uniformly in groups of four, till the four mutually touch, while the different kinds of spheres continue in contact. The assemblage formed in this way may be regarded as consisting of groups each composed of eight spheres, four of each kind tetrahedrally arranged (fig. 10). In it each large sphere is in contact with six small ones,

Fig. 10.

and also with three large ones, making nine contacts, and each small sphere has six contacts as in the previous case.[2] The type of

---

[1] See p. 547.

[2] The centres of the spheres in a closest-packed homogeneous structure of this kind do not *precisely* give a possible equilibrium arrangement for mutually-repellent particles of two kinds, because the equality of the distances between the centres of the spheres of different radius which touch one another would then involve equality of the repulsions subsisting between the two different kinds of particles placed at these centres, and this equality does not necessarily exist in the modified arrangement referred to. For each force which acts on a particle is not now, as in the previous case, balanced by a similar opposite force, and, for the forces which act on a particle to be in statical equilibrium, they must bear certain ratios to one another which depend on their mutual inclinations. And in the case before us these inclinations are such that the pressures between nearest different particles, and therefore their distances apart, will have to form two different sets which are not alike, but slightly different one from the other. A slight modification of the arrangement of the sphere-centres is therefore necessary to obtain the actual equilibrium arrangement possible for two kinds of particles in the case under consideration, but this modification will be one which is quite symmetrical (compare p. 529).

homogeneous structure to which such an assemblage belongs is that numbered 7b₁ in my list.[1] The generic symmetry is that of class 30 in Sohncke's list.[2] The two kinds of balls are, as in the last case, present in equal numerical proportions; each kind of centre forms a singular point-system, all centres lying on trigonal axes, and also in planes of symmetry. All the balls are operative.[3] There is an important difference between this case of closest-packing, and the cases for two kinds of balls previously given. In the latter no kind of partitioning of the structure into unit groups of balls is possible which is not arbitrary, and, owing to its incompatibility with the coincidence-movements (Deckbewegungen), productive of a lowering of the type of symmetry. In the present case, partitioning into groups of the form A_4, B_4 can take place without lowering the type.[4]

Case of gyrohedral hemihedrism of the cubic system.

Again, the radii of two different sets of spheres may be so proportioned that the closest-packed mixed[5] arrangement is of the following kind :—
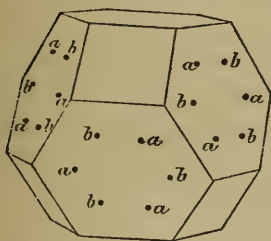
Fig. 11.

Partition space with maximum regularity into similar plane-walled cells, whose centres are *at the centres and angles* of a cubical partitioning of space; these cells will be octahedra truncated by cubes in such a way as to reduce the octahedron faces to regular hexagons (fig. 11).

Join three alternate angles of each of the hexagonal interfaces, selecting the angles symmetrically, and bisect the lines thus drawn. There are two ways of doing this (*a* and *b*, fig. 11, in which only the bisecting points are shown).

At the points of bisection of one set thus obtained, place the centres of spheres whose diameter is such that they touch one

---

[1] Zeitschr. für. Kryst., 23, p. 52.   [2] Zeitschr. für Kryst., 20, p. 467.

[3] See p. 547.

[4] See Mineralogical Magazine, vol. xi., p. 130. Comp. *post*, p. 587.

[5] Some sort of linking will most likely be requisite for this kind of packing to obtain; the massing of each set *by itself* in closest-packing will probably demand less space than any mixture of the two kinds of the nature here described.

another, three and three in the planes of the hexagonal interfaces ; it will be found that the triplets of spheres thus obtained also touch one another in points which lie four and four in planes parallel to the square interfaces of the system.

About each of the centres of the similar cells into which space has been partitioned, then group six equal spheres in close order, *i.e.*, in octahedral grouping ; each octahedral grouplet to have its centre at the centre of the cell which contains it, and to have the same orientation as that of the latter, and the size of the spheres to be such that they touch the spheres already placed whose centres lie in the hexagonal interfaces.

In the system thus formed every sphere of the central grouplets is in contact with four similar spheres, and four others, making eight contacts, and the spheres whose centres lie in the hexagonal interfaces are each in contact with four of the same size, and two others, making six contacts.[1] The type is that marked 13 in my list,[2] and it has the generic symmetry of class 29 of Sohncke.[3] The two kinds of centres are present in the numerical proportions 1 : 2. Each kind forms a singular point system, the less numerous lying on tetragonal axes, the more numerous on digonal axes.

There are two closest-packed arrangements of the same spheres, one of which arrangements is the mirror-image of the other. One is obtained by taking points *a*, fig. 11, the other by taking points *b* for the places of the sphere-centres of one kind.

Case of dodecahedral hemihedrism of the cubic system.

Within each cell of the space partitioning of the last example place the centres of twelve equal spheres at equal distances from the centre of the cell on lines joining this centre with the middle points of the twelve edges in which the octahedral faces meet, and let the equal distances referred to and the magnitude of the spheres be such that the latter touch one another, and also the spheres

---

[1] As in the previous case, the centres of the spheres in the homogeneous structure thus described, will not precisely give a possible equilibrium arrangement for particles of two kinds, the necessities of statical equilibrium precluding this, but a slight modification of the arrangement of the sphere-centres which does not alter the type of symmetry will give a possible arrangement.

[2] Zeitschr. für Kryst., 23, p. 22.	[3] *Ibid.*, 20, p. 466.

similarly placed in the nearest surrounding cells.   Then, as in the last example, within the cavities which exist about the centres of the cells, insert octahedrally-arranged grouplets, containing six spheres each, of such smaller magnitude that they touch the spheres first placed.   Each of these smaller spheres will then be in contact with four of the same set and four of the larger set, while each of the larger spheres will be in contact with two of the smaller set, and eight of the larger set.

The packing of such an assemblage is very close, but if we compare the shape of a single compound grouplet with the shape of one of the cells, it is easy to see that there is a slight openness of the packing at the square interfaces of the cells, that there is a hollow space between the four spheres lying on the one side of such a face and the four spheres lying on the other side.   If now at each square interface the centres of two diagonally-placed spheres on one side and those of the two spheres opposite to them are symmetrically moved slightly towards one another, all four centres continuing in the same plane of symmetry, the hollow places in the arrangement can be contracted and a possible equilibrium arrangement[1] for balls of two kinds can in this way be obtained, in which the centres referred to form a series of similar twelve-point groups, which have planes of symmetry parallel to the cube faces.

The type of the arrangement thus indicated is that marked $10a_1$ in my list.[2]   The generic symmetry is that of class 31 of Sohncke.[3]   The two kinds of centres are present in the numerical proportions $1 : 2$; each forms a singular point system, the less numerous centres lying on digonal axes and in planes of symmetry and the more numerous in planes of symmetry.

Case of holohedrism of hexagonal system.

If a stack of equal spheres is made, consisting of plane layers triangularly arranged in contact, placed so that the spheres of the different layers are vertically over one another, a number of similar interstices are left between the spheres.   Place now in these interstices smaller spheres whose radius is such that they

---

[1] But see Note 5, p. 551.   [2] Zeitschr. für Kryst., 23, p. 45.   [3] *Ibid.*, 20, p. 467

just fit into them. Each large sphere will then be in contact with eight of the same size and twelve of the smaller size, and each small sphere will be in contact with six of the larger spheres. Such an arrangement would appear to give closest-packing for spheres of two sizes thus proportioned.

The type of homogeneous structure is that marked 25a[1] in my list.[1] The generic symmetry is that of class 9 in Sohncke's list.[2] The two kinds of centres are present in the numerical proportions 1 : 2. Each kind forms a singular point system, the less numerous kind lying at the point of intersection of hexagonal and digonal axes and planes of symmetry, and the more numerous at the points of intersection of trigonal and digonal axes and planes of symmetry.

Case of rhombohedrism.

In the closest-packed arrangement of spheres of two different radii, referred to on page 549, the centres of one set occupy the centres, and the centres of the other set, the angles of the cubes of a cubic partitioning of space. Suppose now that we have two sets of spheres whose radii are nearly in the proportion requisite for this arrangement, but that the smaller are rather too small for the purpose. Closest-packing will then probably be attained in an acute rhombohedral arrangement, in which each of the larger spheres is in contact with six of the same size and six of the smaller size, and each of the smaller spheres is in contact with six of the larger ones, this arrangement being derived from the cubic one just referred to by a slight relative elongation of the assemblage in the direction of a cube diagonal and uniform contraction in directions transverse to this.

The type of homogeneous structure presented is that marked 52a[1] in my list.[3] The generic symmetry is that of class 12 in Sohncke's list.[4] The two kinds of centres are present in equal numbers. Each kind forms a singular point system, the centres all lying at the points of intersection of trigonal and digonal axes and on lines of intersection of planes of symmetry.

---

[1] Zeitschr. für Kryst., 23, p. 45.   [2] *Ibid.*, 20, p. 460.
[3] Zeitschr. für Kryst., 23, p. 47.   [4] *Ibid.*, 20, p. 461.

Case of hemimorphism of rhombohedral symmetry.

If tetrahedrally arranged grouplets, each composed of four equal spheres in contact, be so placed at the centres of the cubes of a cubic partitioning of space that the axes of the grouplets coincide with the diagonals of the cubes, the grouplets being all similarly orientated, and if the spheres are of such magnitude that the grouplets touch one another, then it will be found that the spheres have the closest-packed arrangement of figs. 1 and 2.

Suppose, now, that instead of all the grouplets being composed of spheres of the same size, half of them symmetrically placed—*i. e.*, placed about the centres of one of the half systems of cubes which touch one another at their edges only—are composed of rather smaller spheres. The cubic arrangement will not now give closest-packing; for if the largest grouplets be placed as in the case just referred to, the smaller ones will be just too small to fill the spaces allotted to them. Closest-packing for a mixed assemblage[1] will, however, probably be reached if, keeping the grouplets intact, a slight contraction of the assemblage along the direction of one of the cube diagonals be made so as to obtain additional contacts, still keeping the structure homogeneous.[2] The type of homogeneous structure thus obtained is that marked $51b_1$ in my list,[3] and it has the generic symmetry of class 19 in Sohncke's list.[4] The two kinds of centres are present in equal numbers.

It is evident that in an equilibrium arrangement of this nature, centres of the same kind do not all occupy similar positions in the structure; one out of every four centres of each kind lies on a trigonal axis in which planes of symmetry intersect one another, and each of the remaining three centres of each group of four lies in a single plane of symmetry. While therefore all the centres form singular point-systems, two of these systems contain fewer points than do the remaining two.

---

[1] See note 5, p. 551. [2] See note 1, p. 531.
[3] Zeitschr. für Kryst., 23, p. 55. [4] *Ibid.*, 20, p. 463.

Case of trapezohedral tetartohedrism.

If the radii of two sets of equal spheres are in a certain ratio, we are able to build them together into a very closely-packed homogeneous assemblage of the type numbered 52 in my list,[1] whose axes and coincidence-movements are those of system 22 of Sohncke. The arrangement of the centres of the two sets of spheres is difficult to indicate on a diagram; the larger have their centres on digonal axes, and are therefore half as numerous as the smaller ones. Each larger sphere is in contact, or nearly in contact, with fourteen surrounding spheres, each smaller one nearly in contact with ten.[2] The generic symmetry is that of class 15 in Sohncke's list of Krystallklassen. The two kinds are present in the numerical proportions 1 : 2 and the centres of the less numerous form a singular point-system.

Fig. 12.

The balls may be all unlinked, or they may, consistently with the symmetry, be linked together to form similar groups of three, one of one kind and two of the other. If they are thus linked a slightly modified arrangement will be appropriate, and groups of three interpenetrating spheres,[3] two of one size and the third of another, will be used to build up the type of symmetry. An arrangement of the sphere centres such as may be presented in this case is depicted in fig. 12, the methods employed by Sohncke

---
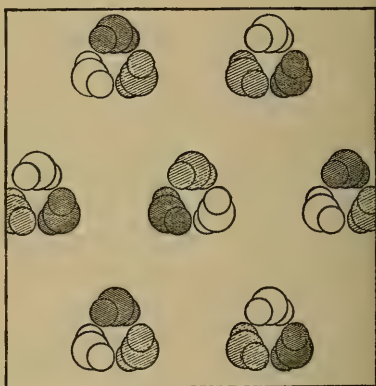
[1] Zeitschr. für Kryst., 23, p. 32.

[2] For the reason stated in a previous example, the centres of the spheres do not precisely give a possible equilibrium arrangement for particles of two kinds, but a slight modification of the arrangement of the sphere-centres which does not alter the type of symmetry, would appear to satisfy the necessities of statical equilibrium and give a possible arrangement.

[3] Compare p. 530.

to indicate that the centres are at different distances from the plane of the diagram being followed and no attempt being made to show the spheres themselves or the way in which they touch one another.[1]

We have in this case most of the symmetrical and other conditions which are met with in quartz-crystals, including a composition and grouping which agree with the molecular composition of that body, and screw-movement axes which involve a spiral arrangement of the parts such as is requisite to account for the property of rotation of the plane of polarization.

Case of bipyramidal hemihedrism.

Take a stack of close-packed spheres, such as is described on page 534 and in fig. 3, and, keeping the spheres which are nearest to each hexagonal screw axis in contact both laterally and longitudinally, separate the stack into strings of triads of spheres by slightly increasing the distances between the axes in a uniform manner.

Orientate all the strings of triads uniformly about the respective axes so as to bring some of the separated spheres again into contact. Finally, place in each of the largest interstices now left between the spheres a sphere of some other radius as large as possible.

It is probable that such a value can be selected for the ratio of the sizes of the two kinds of spheres in an assemblage of the kind just described as will make it the closest-packed mixed arrangement for spheres whose magnitudes bear this proportion. The type of homogeneous structure produced in this way is numbered $20a_1$ in my list;[2] all the centres lie at singular points, the more numerous in planes of symmetry and the less numerous on trigonal axes. The generic symmetry is that of class 11 in Sohncke's list of Krystallklassen. The two kinds of balls are present in the numerical proportions 2 : 3.

---

[1] Compare fig. 22, Taf. II. in Sohncke's Entwickelung einer Theorie der Krystallstruktur.

[2] Zeitschr. für Kryst., 23, p. 45.

A case of holohedral rhombic symmetry.

Place a number of equal spheres in the same plane in triangular order in contact with one another. On this layer, place a second layer composed of rather larger spheres half as numerous; the most even distribution of these which brings them over the spaces between the spheres of the first layer is indicated in fig. 13, the centres of the first layer being indicated by the plain points, those of the second layer lying over the points marked with an asterisk.

The latter centres are nearly equidistant, and slight relative movements would make them so. Consequently if an appropriate relation subsists between the radii of spheres of two sizes and the two kinds are linked into groups in some way, they will probably pack closest when the centres of alternate layers have approximately the relative situations shown in the figure. Neither of the two kinds of layers will, however, have precisely the regular triangular arrangement, and the assemblage, as a whole, will display rhombic symmetry. The type of homogeneous arrangement is numbered $53a_1$ in my list.[1] The generic symmetry is that of class 6 in Sohncke's list of Krystallklassen.
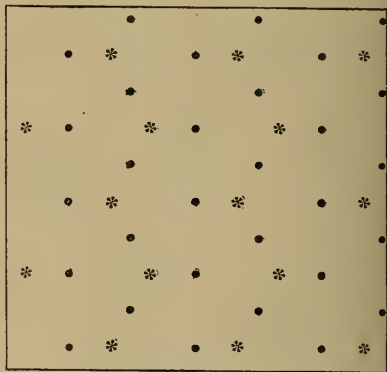
Fig. 13.

The two kinds of balls are present in the numerical proportions 1 : 2. The positions in the structure occupied by the more-numerous are of two different kinds; all the ball centres form singular-point systems the points of which are on digonal axes which lie in planes of symmetry. It is interesting to notice how little removed the assemblage is from being hexagonal—one among many instances of a low type of symmetrical arrangement possessing features more or less similar to those of some higher type.

---

[1] Zeitschr. für Kryst., 23, p. 47.

Case of holohedrism of the monoclinic system.

The arrangement of alternate layers in a stack of equal spheres whose disposition is described in p. 534, is depicted in figs. 3 and 14. Such a stack can be partitioned into octahedral grouplets containing six spheres each, as indicated in the figure, each sphere being in contact with four others of the same grouplet, and the centres of the grouplets forming a triangular-prismatic space-lattice.

Suppose now that, instead of employing equal spheres, we take spheres of two sizes, and form two sets of octahedral grouplets, one composed of the smaller spheres, the other of the larger, and pack the grouplets as closely together as possible, the general plan of the grouping of the spheres of two sizes on plane being of the nature indicated by the letters A, B, in the figure.[1]

Fig. 14.

If the relative magnitude of the spheres of two kinds be such that the centres of one kind of similar groups in the same layer approximate closely to a square arrangement, the centres of the other kind of group falling therefore at the middle points of the squares, it is evident that a very close-packed arrangement is obtained when the centres of the large grouplets of one layer lie about over the centres of the small grouplets of the succeeding layer. There will, however, be some slight racking or shifting over of the assemblage owing to the spheres employed being of two sizes. The symmetry of such an arrangement is monoclinic. The type of homogeneous structure presented is numbered $63a_1$ in my list.[2] The generic symmetry is that of class 3 in Sohncke's list of Krystall-klassen. The two kinds are present in equal numerical proportions.
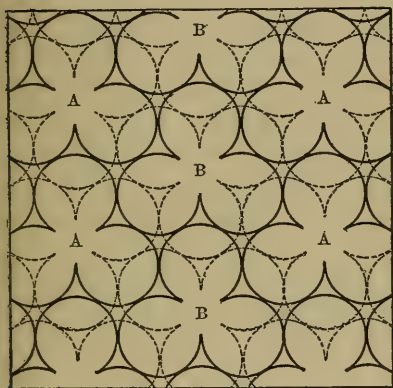
---

[1] Probably a linking of the two kinds of balls to one another must be postulated to prevent closest-packing leading to the formation of two distinct assemblages one of each kind.

[2] Zeitschr. für Kryst., 23, p. 48.

One out of every three centres of each kind lies in a plane of symmetry, and the centres thus distinguished, therefore, form two singular point-systems. The axes are parallel to the plane of the diagram and horizontal; the planes of symmetry are perpendicular to the plane of the diagram through vertical lines.

A second case of holohedrism of the monoclinic system.

If in a stack of spheres arranged for holohedrism of the hexagonal system in the way described on p. 553, the smaller spheres are just too small to fill the cavities containing them, the grouping referred to will not give closest-packing, but if the system be canted over slightly, and the spacing of the spheres in the layers be very slightly modified in an appropriate manner, an arrangement which is probably a closest-packed arrangement can be obtained which is an example of holohedrism of the monoclinic system. The type of homogeneous structure is that marked $64a_1$ in my list.[1] The generic symmetry is that of class 3 in Sohncke's list of Krystallklassen; the two kinds are present in the numerical proportions 1 : 2. Centres of the same kind do not all occupy similar positions in the structure.

C. *Formation of homogeneous assemblages when the balls are of three kinds.*

Case of tetartohedrism of the cubic system.

Partition all space into equal cubes.

Place similar tetrahedral grouplets, each consisting of four equal spheres in contact with each other, so that their centres occupy the centres of the cubes.

Similarly place tetrahedral grouplets composed of spheres of another size at all the cube angles.

Finally place tetrahedral grouplets composed of spheres of a third size at all the middle points of the cube edges.[2]

If all the grouplets are similarly orientated, and their axes have the four directions of the cube diagonals, sizes can be selected for the three sets of spheres which will give very close packing in the

---

[1] Zeitschr. für Kryst., 23, p. 48.

[2] Or at all the middle points of the cube faces, the latter having the same situations relatively to the cube centres as the middle points of the cube edges have relatively to the cube angles.

arrangement described. A yet closer packing is however, attainable if all the grouplets of the third set experience a slight symmetrical rotation about their centres, the rotation being of such a nature that all the four spheres of each of these grouplets continue to occupy similar positions in the four cubes which meet in the cube edge.

In the closest-packed system of spheres of three sizes that can be arrived at in this way,[1] it will be found that each cubic cell of the space-partitioning contains a similar arrangement of the spheres, the sphere centres of the first and second sets lying, in each case, at the angles of a regular tetrahedron, and the sphere centres of the third set forming a " 12—punkter " of Sohncke.[2] The type of homogeneous structure is that marked 7 in my list,[3] and it has the generic symmetry of class 32 in Sohncke's list of Krystallklassen. The two sets of less-numerous centres form two singular point-systems whose points lie on trigonal axes. The three kinds of balls are present in the numerical proportions 1 : 1 : 3. There are two equilibrium arrangements of the same spheres, one of which is the mirror image of the other. Centres of the same kind occupy similar positions in these arrangements.
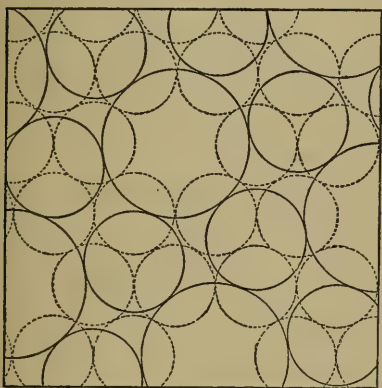
Case of pyramidal hemihedrism of the hexagonal system.

Arrange a plane layer of equal spheres touching one another, but with symmetrically-situated gaps as shown in fig. 15, the gaps having a triangular arrangement.

Fig. 15.

---

[1] There will probably have to be some linking, see note 5, p. 551.

[2] As in some of the previous cases, the centres of the spheres in the closest-packed homogeneous assemblage of spheres thus indicated will not precisely give a possible equilibrium arrangement for mutually-repellent particles, this being precluded by the necessities of statical equilibrium. (Compare note 2, p. 550).

[3] Zeitschr. für Kryst., 23, p. 18.

Over these gaps place equal spheres of greater size, and over the points midway between them a second set of equal spheres smaller than those over the gaps, the size of the spheres in the two sets being such that their centres lie in the same plane and that they are in contact.

On the second layer thus formed place a third layer similar to the first and vertically over it, and then a fourth similar to the second in like manner, and so on.

In such an assemblage each smaller sphere is in contact with five of the same size, two of the medium size and two of the large size; each medium-sized sphere is in contact with six small and three large; each large sphere with twelve small and six medium-sized.[1] The type of homogeneous structure presented is numbered 23a$_1$ in my list.[2] The generic symmetry is that of class 11 in Sohncke's list of Krystallklassen. The three kinds of centres are present in the proportions 1 : 2 : 6. All the centres occupy singular points, those of one of the two less numerous kinds lying on hexagonal axes, those of the other on trigonal axes, and all in planes of symmetry.
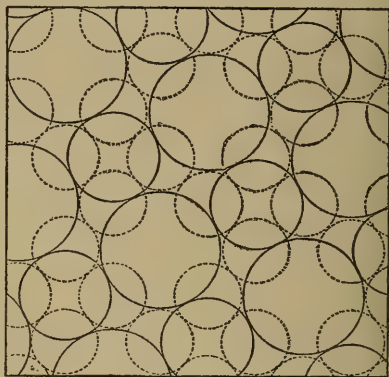
Fig. 16.

Case of pyramidal hemihedrism of the tetragonal system.

Arrange a plane layer of spheres in close square order, but with gaps as shown in fig. 16. Over these gaps, and also over the points midway between them, place other spheres in contact with those first placed of such radii that their centres all lie in the same plane, and that they touch one another.

On the second layer thus formed, place a third layer similar to the first and vertically over it, and then a fourth similar to the second in like manner, and so on.

---

[1] See note 5, p. 551. [2] Zeitschr. für Kryst., 23, p. 45.

Each smallest sphere is then in contact with three of the same size, and two of each of the larger size. Each larger sphere of either size is in contact with eight small, and four of the other larger size.[1] The type of homogeneous structure presented is numbered 34a₁ in my list.[2] The generic symmetry is that of class 23 of Sohncke's list of Krystallklassen. The three kinds of centres are present in the proportions $1 : 1 : 4$.[3] All the centres occupy singular points, those of the less numerous kinds lying on tetragonal axes, and all in planes of symmetry.

The foregoing examples of closest-packing of one, two, or three different sizes of balls must suffice. To give anything like a complete review of the ways in which a fortuitous assemblage may be converted into a homogeneous assemblage as a consequence of closest-packing, we shall have to deal with cases of the combination of four, five, six, &c., different sixes, and *to greatly multiply instances in which particles of more than one kind are linked together to form a number of similar groups.* This additional supposition often leads to a considerable increase of complexity which makes the results difficult to trace, while at the same time the number of possible solutions is greatly multiplied. Several, however, of the cases above described have been, and others can, as will subsequently be pointed out,[4] be treated as those of assemblages of identical groups of linked particles ; and it is easy to see that in cases of more complicated assemblages of groups of linked particles, as well as in the simpler cases here given, closest-packing will frequently lead to homogeneity of arrangement.

Without citing other cases, enough has been said to establish the general conclusion that closest-packing of an assemblage of balls of one, two, three, &c., different kinds will, under the conditions defined, very commonly lead to the production of some *homogeneous* arrangement or arrangements, the variety of form possible being very great indeed. All homogeneous structures whatever have

---

[1] There will probably have to be some linking, see note 5, p. 551.

[2] Zeitschr. für Kryst., 23, p. 45.

[3] As a fact which may have some significance, it may be noted that several bodies which crystallize in the symmetry referred to have a composition of the form A B C₄.

[4] See pages 586 *et seq.*

been shown by the author[1] to possess the generic symmetry of one or other of the thirty-two classes of crystal-symmetry.

In most of the instances of symmetrical arrangement above traced it is not easy to determine with certainty whether we have arrived at a system which can give stable equilibrium or not, but there is a high probability that in very many cases stable equilibrium is attainable in the arrangement described without any linking being premised, if certain appropriate relations between the repulsions be chosen. In any case we have established the following proposition :—

That assemblages belonging to all of the thirty-two classes of crystalline symmetry result from closest-packing of balls of different sizes, when the relations between the different radii take the widest possible range of variety, and cases of packing together of spheres formed into groups in the way premised are included, as well as the cases in which the spheres are unlinked.

This proposition has, as has just been intimated, been established from a consideration of comparatively simple cases; the employment of more complicated assemblages would lead to the same conclusions.[2]

An examination of some results corresponding to the facts of stereo-chemistry which is undertaken later[3] will show that in some of these more complicated assemblages the centres of the same kind occupy enantiomorphously-similar, as well as identically-similar, positions, like the points of a Fedorow-Schönflies " doppeltes System."[4]

The spread of symmetrical arrangement in an assemblage.   Crystal growth.   Bent and branched crystals.

If a process of close-packing, due to the interaction of its parts, is the agency by which an assemblage becomes arranged symmetrically, it is evident that the solidification, *i. e.*, complete linking up of the parts which produces a rigid homogeneous assemblage, is not strictly concurrent with, but *subsequent in time* to, the arrang-

---

[1] Zeitschr. für Kryst., 23, p. 1.   [2] See note 1, p. 533.
[3] See pp. 582 *et seq.*   [4] Zeitschr· für Kryst., 23, p. 41.

ing process. For in order that the arrangement may take place as a consequence of the interaction of the parts which are taking up symmetrical situations, there must, it is manifest, be *a more or less extensive tract of matter in an unlinked or partially unlinked,* i.e., *in a fluid condition, in which symmetrical arrangement is being achieved, but not rigidity.* There must, in other words, be a state, which may, however, be quite transitional, which is *a symmetrically arranged fluid state.*

Again. If such a fluid tract be bounded *on one side* by a portion of the same assemblage, of the same composition, which has passed into the completely rigid state, but on the other sides is not so bounded : it is evident that at the side next to the rigid portion, if the latter have retained the same or nearly the same density, the parts or particles will, as they pack closely, take up positions in harmony with those of the particles composing the rigid portion, and will consequently here arrive sooner at a condition of stable equilibrium, and so experience less continual disturbance or re-arrangement than those do which are further removed from the solid portion.

On the other hand, if the fluid tract be in contact with a solidified assemblage which is *unhomogeneous,* it is evident that the condition of special tranquillity which prevails where the fluid and solid meet when they are congruent will not be experienced.

As in harmony with these conclusions, one may cite the existence of crystalline liquids (krystallinische Flüssigkeiten), *i.e.,* of a liquid state of some bodies in which a definitely arranged symmetrical structure, as evidenced by their polarizing properties, is associated with complete fluidity.[1] And the rarity of this phe-nomenon can hardly be said to diminish its suggestiveness. For a single well-established instance of the production of crystal properties apart from rigidity suffices to show that the latter is not essential, *and may in all cases follow, and not accompany,* the arrangement of ultimate parts which gives crystal properties.

Parallel to the above conclusion that if, in a homogeneous

---

[1] Lehmann, " Ueber fliessende Krystalle." Zeitschr. für physikalische Chemie 4, p. 462 ; and by the same author, " Die Struktur krystallinischer Flüssigkeiten." The same Zeitschr., 5, 427.

assemblage of mutually-repellent particles, a portion have passed into the rigid state, we shall have a tract or film of the portion still fluid lying next to the solidified portion, and which is in a more tranquil state, and further advanced towards stable equilibrium than the rest, we have the fact that it is the portion of the crystallizing liquid nearest to the crystal which commonly passes to the solid state first. In other words, crystals grow by accretion, while amorphous bodies do not.[1]

The tract of maximum tranquillity and symmetry which we have concluded must lie next to solidified portions of the assemblage will, it is evident, to some extent be broken up if the continuity of structure of the solidified surface is partially destroyed by rupturing the solid and disarranging the broken portions. For a symmetrical arrangement of the film of liquid in harmony with one portion of the body will not then be in harmony with a neighbouring portion. A very significant fact with regard to crystals may be cited to compare with this.

If a crystal, *e.g.*, of ammonium chloride, be beaten out, and then placed in its solution and allowed to grow, it is found that the accretion at the boundary, where the solid particles are in contact with the solution, takes place *in skeleton form*[2] showing that *the disturbing influence of a fracture and displacement on the process of crystallization extends to a considerable distance from the fracture in both directions in the adjacent film of solution.*

The transition state, in which the symmetrical arrangement, but not the solidification of an assemblage is taking place, is

---

[1] The alternative theory of crystal formation supposes each particle added to the growing mass to take up its symmetrical situation *not before,* but at the time it is attached to the previous growth, just like a brick added to a wall in building. This view seems perhaps at first sight to be countenanced by the discovery made by Wulff that better and more regularly formed crystals can often be obtained when a solution is in motion that when it is at rest. That it is not supported by the fact referred to is seen, however, when we consider that the places of *minimum* disturbance will still, notwithstanding the motion, be close to the crystal surfaces, and that while the disturbance operates to prevent irregular growth, *it does not preclude the existence of films of the crystallizing substance in a more or less liquid condition adhering to the already solidified crystal surfaces from time to time formed, and remaining undisturbed by the motions.* (See Wulff, Zeitschr. für Kryst., 11, p. 120.

[2] Lehmann "Ueber fliessende Krystalle" Zeitschr. für physikalische Chemie 4, p. 467 and fig. 3.

necessarily one of gradual change from the moment when the first indications of orderly arrangement present themselves till the most perfect symmetry is achieved. And if the opposing forces, the arranging force and the disturbing force which produces fluid motions, are subject to any ebb and flow, it is conceivable that *after some amount of orderly arrangement has been achieved the fluid motions, instead of uniformly subverting this symmetry, will merely so far break up the partially-arranged mass as to reduce it to fragments which roll upon and round-off one another;* these fragments preserving internally the degree of symmetrical arrangement which has been already imposed, and the space between them being occupied by less-regularly arranged aggregates of particles of the same or of some different composition.

The rounded crystalline grains whose presence in many cases marks an intermediate stage of crystallization from solution, and which have been called *globulites* and *crystallites*,[1] may be mentioned in this connection as furnishing a possible parallel to the condition just traced, but the composition of the bodies referred to is very possibly, in some cases, due to impaired homogeneity, the nature of which we are about to consider.[2]

Where a homogeneous assemblage in which, under slow change of conditions, a very gradual spread of solidification is taking place, is continuous, and but little disturbed by outward influences, we shall expect the accretion at the growing surfaces to proceed with much uniformity, and especially that at every surface throughout which the conditions are uniform the growth or increase will also be uniform. And it is obvious that the extremely regular progress of crystallization in continuous masses subject to very uniform conditions and very slow change is entirely in harmony with this expectation.

Further, if the general conditions change but slowly, considerable disturbing movements of the liquid portion of a homogeneous assemblage may not prevent the accretion to the solid portion from being extremely uniform *so long as the slowness of the change of*

---

[1] See "Die Krystalliten" von H. Vogelsang. Bonn, 1874.

[2] See p. 568. Compare Heinrich Vater " Ueber den Einfluss der Lösungsgenossen auf die Krystallisation." Zeitschr. f. Kryst. 27, p. 477.

conditions is such that every part of the surface of the growing solid experiences on the whole the like conditions.[1]

If, however, the change is not sufficiently slow to give this uniformity of conditions in a fluid assemblage at different points of the boundary of a solidified portion of it, some departure from uniformity of accretion is to be looked for.

This will especially be so if the fluid assemblage which is of the same composition as the mass already solidified is more or less fragmentary and interspersed among portions of differently-constituted fluid assemblages which are not partaking in the solidifying change. For although in this case the place of maximum tranquillity, *i.e.*, the surface of the growing solid, will still be the place of growth, *the relative rate of growth* at different parts of this surface will be regulated chiefly by the relative distribution or supply of the material for growth, and the supply of material being different at different places the growth will be irregular

As irregular growth thus caused is, however, a matter which does not come within the scope of our investigation, this interesting topic must be dismissed with the remark that Lehmann's investigation of the nature and causes of the growth of skeleton crystals seems to the author to be entirely satisfactory.[2]　　This remark is intended, however, to apply only to the cases of irregular growth in which the structure is congruent—to skeleton crystals but not to bent or branched crystals. As we shall see immediately, closest-packing is capable of producing bent and branched assemblages which are very nearly homogeneous, although it is of course impossible for them to be quite so.

Impaired Homogeneity—Bent and Branched Crystals.

We have hitherto in these pages regarded mixed assemblages of balls which are subjected to a process of closest-packing as forming two great divisions—division 1, to which this section is especially devoted, comprising all those in which closest-packing is attained in a homogeneous arrangement, and division 2 those

---

[1] Compare *ante*, note 1, p. 566.

[2] O. Lehmann "Ueber das Wachstum der Krystalle." Zeitschr. für Kryst., 1, p. 453, especially page 471.

which, while they may approximate to a general uniformity of distribution, cannot reach homogeneity, and are unable to arrive at stable equilibrium.

Now, although it would appear that these two divisions embrace all possible cases of assemblages whose dimensions are *large*, a little consideration shows us that for *thin* assemblages, *i.e.*, those in which either one or two of their three dimensions are small, *slightly impaired homogeneity, not incompatible with stable equilibrium within the assemblage, may give closest-packing.*

The following will make this clear in a single instance :—

If in a cubic partitioning of space spheres of one size be placed at the cube centres, and spheres of another size, bearing a certain proportion to the first, at the cube angles so as to form a stack such as is described on p. 549 (fig. 9), this stack may be regarded as made up of triangularly-arranged layers, each composed of one kind of sphere only ; the planes of these layers are perpendicular to some one of the four directions of the cube diagonals, and alternate layers are composed of spheres of the same size.

Suppose now that instead of spheres of two sizes only, four different sizes are used, and, instead of an infinite number of layers but four consecutive triangularly-arranged layers are present. It is then evident that if we preserve about the same proportion between the sizes of succeeding layers as prevails in the stack just referred to, *but make the spheres of the third layer a very little smaller than those of the first, and those of the fourth with a similar relation to those of the second,* closest-packing will be reached, not when the centres of the equal spheres of a layer lie in the same plane, *but when they lie on some curved surface very approximately spherical,* the four different surfaces traced by the centres in the different layers being practically concentric. Since the curvature of the layers is very slight, as compared with the sizes of the spheres, the departure from uniformity in the arrangement of a layer caused by its following a curved surface instead of a plane will be but trifling, even in the case of layers of considerable extent.

Further, if, instead of one set composed of four layers, the assemblage consists of several such sets, it is evident that an effect of the same kind may be looked for, although in this case, for the arrangement to be congruent, the conditions in each curved

shell composed of four layers will be slightly different. Where a limited number of similarly constituted shells are present in an assemblage of the nature indicated, there may be very little difference in the closeness of the packing of the different shells if the *increments* of the distances between similar ball centres found as we travel outwards from shell to shell, and caused by the increase of circumference, be compensated by an appropriate *decrement* in the radial distances and consequently in the thickness of succeeding shells; the solid contents of the *spaces* contained between the successive corresponding spherical surfaces being thus made equal.

The other kind of *uniform* curvilinear distortion of a thin plate possible, viz. *cylindrical* curving is, it is evident, equally available with the spherical curving just referred to, when suitable homogeneous assemblages are selected for modification.[1]

Besides these two kinds of distortion, *local* distortions producing *local* increase of closeness of packing are conceivable. The effect of these will naturally be the same as that of local shrinkages in thin solid bodies, and like these be productive of local torsional twists.

Finally, a torsional twist, uniform along the length of a capillary assemblage of sufficient fineness, may increase closeness of packing in some cases.

Assemblages consisting of large linked groups will especially lend themselves to the production of the modified homogeneity referred to. Thus wedge-shaped groups will be likely to pack closer when put together to form an arch if the assemblage is a thin one.

A fundamental condition, in all cases, evidently is that the distortion from the corresponding homogeneous arrangement shall not materially shorten or lengthen the distance separating two ball centres which touch one another. For, if it did, the centres could not continue to have approximately the same general arrangement throughout the assemblage.

Applying this condition, we see that if some of the lines which

---

[1] The axes of an assemblage may be *inclined* to the axis of the cylinder. If they are, their directions will, after distortion, become screw-spirals.

join the centres of balls that touch in a thin assemblage lie in a parallel to the surface of the assemblage, we cannot have spherical bending of several layers, because this kind of distortion would involve material differences in the lengths of corresponding lines found in different layers. Such a situation of these lines does not, however, preclude cylindrical bending, provided their direction is that of the axis of the cylinder, for when this is the case their lengths will be unaltered by the distortion.

It is not necessary, or indeed generally possible, that the curving of an assemblage shall present precisely the same degrees of symmetry as would be presented by the assemblage if undistorted, even when the modification of the latter by the limitation imposed on its extent is taken into account. Thus it is conceivable that the holomorphism of a thin assemblage may be impaired by a curvature which is concave towards one end of a holomorphic axis, and therefore convex towards the other end. For although symmetry will require that such a change shall be equally possible in either of the two opposite directions, its occurrence in the one direction in any part of the assemblage may preclude its occurrence in the other in any other part of the same assemblage. Similarly a torsional twist experienced by an assemblage of small extent which is identical with its own mirror-image, may deprive it of the latter property, although the determination of the direction of the twist—whether it shall be right-handed or left-handed, will depend on accident, or at least on external circumstances.

A few words next with regard to the growth or increase of curved assemblages.

The curvature of succeeding uniform layers of a curved assemblage being necessarily different, it is evident that if a particular curvature gives closest-packing, and a very thin assemblage consisting of a very few layers and having this particular curvature be formed *and solidified*, layers added congruently to either face of such a nucleus will be unable to take up the closest-packed arrangement, those on the convex side having their dimensions along the surface rather too large, and therefore the distance between succeeding layers rather too small, and those on the concave side experiencing an unfavourable condition just the opposite of this.

Notwithstanding this, however, we must look for a congruen extension of the assemblage in both directions from the nucleus, because the irregularity and incompatibility which would otherwise be found at the junction of the solid and fluid portions would, at any rate so long as the number of added layers is few, be more prejudicial to closeness of packing *at this boundary* than the modification imposed by the difference of curvature referred to; indeed we reach the important conclusion that *if the curvature is infinitesimal as compared with the distances between contiguous centres, a large number of layers may be added before the departure from the most favourable curvature becomes sufficient to prevent congruent accretion.* Transition is thus possible from molecular thinness to microscopic or even macroscopic dimensions.

Now a slight straightening of the nucleus will, it is evident, favour closest-packing of layers added *on the concave side* by approximating their conditions to those of the favourably arranged nucleus in regard both to the distribution of the centres and the curvature of the layers. Such a straightening will also favour closest-packing of layers added *on the convex side*, so far as distribution of the centres is concerned, but not in regard to the curvature of the layers, the latter becoming still further removed from the most favourable curvature. It is clear, therefore, that in many cases layers added on either side of the bent nucleus will, in striving after closest-packing, exercise some force tending to straighten it, and that as fresh layers are added, this will increasingly be the case. And if the solidified nucleus yields to some extent to the strain thus put upon it without being ruptured, its original curvature will be flattened. And further, if more layers are added at one part than at another we shall have the alteration of curvature different at different places.

If, for example, the number of layers added is greater as we pass from one end to the other of a band-shaped assemblage whose most favourable curvature for closest-packing is a cylindrical bending about an axis transverse to the band, it is evident that the band will take the shape of a watch-spring spiral.

If, when a certain amount of bending has taken place, the solidified portion of the assemblage breaks rather than bend any more, it is evident that the gradual growth of an assemblage will

result in its sudden rupture when a critical point is reached. If, however, it will bend till all curvature is done away we may look for ultimate production of a rectilinear perfectly homogeneous condition of the assemblage as the result of the addition of a large number of layers. If it affords great resistance to bending we may have a case in which the assemblage grows considerably in every direction, while still a curved assemblage.

If skeleton growth, *i. e.*, discontinuous accretion, takes place along a bent surface of the solidified portion of an assemblage of the modified nature now under consideration, it is evident that the curved branches formed cannot be congruent, *i.e.*, cannot form part of a homogeneous whole capable of a congruent filling in of the interstitial spaces. In other words, an unhomogeneous branched assemblage and not a skeleton homogeneous one will result.

The facts concerning curved and branched crystals exactly parallel the conclusions reached above. Bending and branching occur generally when the crystals formed are extremely fine or thin,[1] and consequently only when the conditions are appropriate for the production of such crystals. According to Lehmann these conditions are either rapidity of crystallization, viscosity of the solution, or a low degree of solubility of the crystallizing substance in the solution.

Thus he found that when a hot saturated solution of ammonium chloride, which has been suitably thickened with gum, is cooled, the quicker the crystals are formed and the more the viscosity is increased, the more delicate are the forms of the crystals. And he further found that in order to obtain skeleton crystals of potassium chloride out of aqueous solution, either an extremely thin stratum must be employed or, which attains the object more readily, the viscosity must be increased by the addition of gelatine.

As an instance of the effect of a low degree of solubility, the same writer says of silver chloride, " Small skeleton crystals can be easily obtained by rapid evaporation of its solution in ammonia or sodium chloride solution. Very fine large, well-formed crystals resembling those of ammonium chloride are produced by the

---

[1] Thin, that is to say, as compared with their curvature. It must be remembered that the curvature, considered with regard to molecular magnitudes, is always extremely slight.

solidification of the melted mass or when it is dissolved in melted silver iodide. It may, however, be remarked that the skeleton crystals obtained in the way last mentioned are much more massive than those out of aqueous solutions. Difficulty of solution has therefore much the same effect as viscosity, since it brings about the formation of more delicate forms."[1]

Lehmann tells us that " bending and branching arise almost simultaneously." They are of very common occurrence among cases where very great irregularity in the rate of growth at different places is produced by one or other of the causes just enumerated.

Thus, according to the same author, Isohydrobenzoïndiacetate crystallizes out of alcohol in singular bent crystals resembling frequently a rolled up band. This form is, however, retained only so long as the crystals are sufficiently thin to show interference colours. As they thicken they straighten themselves out more and more, and finally become fine regular rhombic crystals. Besides the bending described, a bending perpendicular to it generally takes place.

Again, if a mixture of chromic chloride with mercuric chloride in aqueous solution is placed on an object glass under a cover and then evaporated till it becomes fairly thick, very long thin capillary crystals are formed as the cooling proceeds, which at first are curled up in spirals, but unroll themselves as they grow thicker.

As a third striking instance, if a solution of wax in naphtha is rapidly cooled, radiated aggregations of very thin plates are at first formed ; these spherolites do not, however, continue long, but give way in the middle, extending themselves to form a ring which then breaks up into several bow-shaped fragments. Each individual of these winds and bends itself as the growth proceeds till at length it again falls to pieces. And all this stretching and bending and fracturing takes place with such energy that the whole crystal mass in effecting these involved movements appears as though alive.

As a final instance cupric chloride may be mentioned. Commonly this substance crystallizes out of acidified aqueous solution

---

[1] O. Lehmann " Ueber das Wachstum der Krystalle." Zeitschr. f. Kryst., 1, pp. 457–459.

in extremely fine needles which bend themselves somewhat vigorously, and then, while strong evidences of tension, sometimes resulting in rupture, show themselves, straighten themselves out. The larger crystals show brilliantly the progress of the formation of branches; directly they impinge on any obstacle, however insignificant, brush-like radiations are formed at the place.[1]

Tetragonal well formed crystals of cromfordite (phosgenite) are sometimes met with which have a spiral twist.[2]

Dimorphism, Trimorphism, &c.

The relative situations taken up by the ball centres of a mixed assemblage as the result of closest-packing depend, as we have seen, on what sizes are brought together.[3] It is evident, therefore, that where there is more than one kind of ball, if a change of conditions occurs which alters the sizes of balls of different kinds differently, the alteration produced may conceivably be such that closest-packing is no longer attained in the type of arrangement which originally gave it. And where this is the case, if the change be made gradually, it will be found that immediately a critical point is passed at which the type of arrangement originally presented ceases to be the closest-packed equilibrium-arrangement, the assemblage will cease to approximate to this original type of arrangement, and will commence approximating to some other different type, viz. to that which after the critical point is passed becomes the one which now gives closest-packing. Whenever a critical point of this kind is passed, an assemblage will, therefore, take up a new type of arrangement, and if both before and after the critical point is passed, the same bodies constitute one homogeneous assemblage, the two assemblages thus presented will be dimorphous assemblages.

At the critical point exactly the assemblage will of course be equally disposed to take up either arrangement, and consequently

---

[1] O. Lehmann, "Ueber das Wachstum &c.," pp. 479–481.

[2] There is an exceptionally fine specimen in the British Museum, London.

[3] But see note 1, p. 546. Some effect in determining the nature of the arrangement is also traceable to the linkage; and this applies to all linked assemblages whether they consist of a single kind of ball or of more than one kind.

if a fluid assemblage in this critical condition is brought into contact with a solidified portion of the same assemblage of practically the same density which displays one of the two dimorphous forms, it will adapt itself to, and become continuous with this form, to the exclusion of the other. Indeed a fluid assemblage capable of dimorphism, if it is *anywhere near* the critical condition referred to will show this readiness to adopt the arrangement of whichever of the two dimorphous forms comes in contact with it in a solid state. For in so doing it will bring about a closer-packing at the place of junction with this solid portion, than it would do if it were not congruent with the latter, even although the result of the congruence is that the fluid assemblage has not, when taken alone, the absolutely closest-packed arrangement possible to it.[1]

An essential difference in the broad features of the various dimorphous changes of which assemblages of balls undergoing alteration in size are capable enables us to classify these changes under two distinct heads. Thus we have :—

1. Dimorphous change which consists in the uniform shrinkage or expansion or shearing in one or two directions of an assemblage taken as a whole, and which is *unaccompanied by any further rearrangement or redistribution of the parts than this involves.*

2. Dimorphous change which consists in a rearrangement or redistribution of the parts *beyond what can be effected by any mere orthogonal projection, or successive projections, or simple shearing of the original assemblage.*[2]

An instance of a change of the nature included under the first of these heads would be presented if an assemblage consisting of two kinds of balls, or groups of balls, placed respectively at the angles and centres of a number of similar parallelopipeda fitted together to fill space without interstices in the most symmetrical manner possible, became so changed that the two kinds came respectively to occupy the angles and centres of similar cubes

---

[1] An effect of the kind above described is also capable of being produced by an alteration in the ratio between the shortest distances separating linked and unlinked centres respectively, and the latter kind of dimorphism may be brought about *in assemblages consisting of a single kind of ball* as well as in those composed of more kinds than one, if an adequate change of conditions takes place.

[2] Compare p. 590.

filling space as symmetrically as possible; thus experiencing a change from the asymmetric to the regular system.[1]

As an example of a change such as would come under the second head may be given that of an assemblage consisting of two kinds of balls present in the proportions 1 : 2 from the gyrohedral hemihedrism of the cubic system described on page 551, to the holohedrism of the hexagonal system described on page 553.

Changes belonging to division 1 may, it is evident, take place in solidified assemblages without doing violence to the ties above defined which constitute their solidity, but it is hard to conceive of changes belonging to division 2 as occurring in a solidified homogeneous assemblage without causing the destruction of these ties; unless indeed the redistribution be of a trivial character.

The changes comprised in division 1 can be subdivided into two classes.

(*a*) Comprising all those in which the change on passing the critical point takes place smoothly, *i. e.*, not *per saltum*.

(*b*) Comprising all cases in which on passing the critical point the assemblage is suddenly found out of equlibrium, and makes a change of form *per saltum* to reach equilibrium in the new type of arrangement.

The following will illustrate the nature of a change of class *a*.

Suppose that we have a stack of spheres of two sizes such as is described on page 547, the larger spheres having the closest-packed arrangement of figs. 1 & 2, and the smaller spheres just fitting into the largest interstices left between these.

If now, keeping the size of the smaller spheres the same,[2] the size of the larger spheres be gradually diminished to a slight extent, so that they can no longer have as many contacts with one another, the stack will, it would appear, continue to be as close-packed as possible *if the separation of the larger spheres takes place in planes drawn through the sphere centres perpendicular to some one of the cube diagonals of the space partitioning*, and the remaining contacts between these larger spheres be preserved intact.

---

[1] This instance is given merely to show the kind of change meant, not as one likely to be realized.

[2] As the effect under consideration depends on a *relative* change of size, this comes to the same thing as changing the size of both kinds.

Now the relative arrangement of the sphere-centres thus reached is produced by a uniform contraction of the cubical arrangement in one of the four directions of the cube diagonals, the arrangement reached being therefore a rhombohedral one. The change experienced takes place smoothly *without any discontinuance of equilibrium*, and it is therefore of the kind marked *a*.

To illustrate the nature of a dimorphous change of the class marked *b*. Suppose that in the stack of spheres of two sizes which has become rhombohedral in the way just explained the ratio between the radii of the larger and smaller spheres continues to fall in value, *and passes the point at which the equilibrium arrangement becomes again a cubic one, viz. that described on page* 549 (and see fig. 9).

Now during all the previous change in the ratio of the radii up to this point the contacts between the larger spheres in the equilibrium arrangement have continued of the same nature, *but directly this point, at which the arrangement a second time becomes cubic, is passed, these contacts become broken,* and it would appear that almost immediately after passing this point, for closest-packing to obtain, the larger spheres must approach one another in planes at right angles to one of the directions of the trigonal axes of the system till they come in contact in these planes. This involves a sudden uniform contraction of the system in all directions at right angles to such an axis and a uniform expansion in the direction of the axis.

The changes of division 2 must, it is evident, be *per saltum*.

If an assemblage passes two critical points in succession at each of which the existing type of equilibrium-arrangement is exchanged for a different type in one of the ways above described, we have trimorphism ; if three such critical points are passed, tetramorphism.

Turning now to the experimental facts we find that these are closely akin to the conclusions reached above. In the first place there is the fact that a mere dimensional change of a crystal which does not amount to dimorphism, *e.g.*, an alteration of bulk caused by change of temperature, is different in different directions except in cases of crystals belonging to the regular system. And, just such a relation between form and dimensional change will be found

in an assemblage consisting of two or more kinds of balls, if the different balls expand or contract at different rates when subjected to some external change of conditions.

The behaviour of sulphur is just what one might expect of an assemblage of mutually-repellent particles when subjected to such changes of conditions as will produce polymorphism belonging to class *b* of division 1.[1] Thus Lehmann says of this body :—" Sulphur, as we know, crystallizes from a melted mass, or out of a hot solution, in monosymmetric forms which, as the cooling proceeds, are transformed more or less rapidly into the rhombic modification, and conversely, the latter when heated passes to the monosymmetric form, as is perceived by the turbidity which displays itself, or still better by the change of colour of a thin lamina in polarized light. And it is easy to keep the temperature at such a point that the boundary of one or the other modification gives way at the slightest change in one or the other direction, *i.e.*, as slight cooling or warming occurs."[2]

And, quoting further from the same author :—" If very hot melted sulphur is rapidly cooled the viscous modification is obtained. In a mass of this kind two kinds of crystals are gradually formed, the characteristically bent ones of a yet unknown modification, and monosymmetric ones which are more spherolitic. On being touched the first are rapidly transformed into the latter. And on being heated they disappear first, and therefore have the lower melting point. If rhombic sulphur is brought in contact with the viscous mass the rhombic crystals grow in the form of fine branched and bent skeleton crystals ; they are, however, quite distinguishable from those of the unstable form just mentioned, especially when the warming takes place gradually, in which case they grow to fine pyramidal groups, while the latter develop to small leaf-like crystals."[3]

As another instance resembling the polymorphism of class *b*, division 1, we have ammonium nitrate which presents four forms,

---

[1] This explanation of the properties of sulphur requires the presence in it of at least two kinds of ultimate parts or particles. If this is regarded as an objection, there is the alternative that similar effects may arise from dimorphism due to linkage. (See note 1, p. 576).

[2] Zeitschr. f. Kryst., 1, p. 112. [3] *Ibid.*, 1, p. 128.

two rhombic, a rhombohedral and a regular form. In polarized light the crystals behave as altogether isotropic. If gradually cooled, however, a change suddenly takes place at about 127°, and they become double-refracting, and as a less solubility is proper to the new form than to the regular one, the change of form is accompanied by increase of size in cases where the crystals are found in a solution. From the rudimentary form and the optical behaviour it can be concluded that the crystals obtained in this way are Frankenheim's rhombohedra.

If the solution is further cooled, at about 87° needle-shaped rhombic crystals are produced. The regular situation of these with relation to the rhombohedral ones, as the latter are spontaneously transformed, furnishes an exceptionally good example of the phenomenon that when a transformation from one modification into another takes place, the newly-formed has in general a regular situation with respect to the older modification. Thus in the present instance the crystals are so placed that the vertical axis of the rhombic form, that which corresponds to the greatest extension, either has the same direction as that of a secondary axis of the rhombohedral form, or is at right angles to it, while the macro- or brachy-diagonal,[1] has the same direction as the principal axis of the rhombohedron.[2]

The readiness with which an assemblage of mutually-repellent particles, or spheres,[3] will respond to a change of conditions past a critical point, and commence approximating to a different type of arrangement will, it is manifest, depend not only on what it comes in contact with, but will also partly depend on the amount of disturbance to which it is subjected.[4] And for comparison with this may be mentioned Lehmann's remark with regard to the transformation from one solid modification to another. "When a modification is heated while isolated it is sometimes possible to raise the temperature far above the point (normal critical point of temperature) at which, when in contact with a crystal of the

---

[1] It is impossible to determine which, as the prism of the rhombic crystal is nearly right-angled.

[2] O. Lehmann "Ueber physikalische Isomerie"; Zeitschr. f. Kryst., 1., p. 107; Comp. Pope's translation of Fock's "Chemische Krystallographie," p. 158.

[3] See p. 529, especially note 2.   [4] Comp. No. 7 of Data, p. 688.

modified sort, transformation commences, but mechanical shaking is generally competent to bring about the change."

Of other dimorphous substances whose behaviour would appear to resemble that which has just been attributed to dimorphous assemblages belonging to division 2, Lehmann speaks as follows:— " The rest of the substances belonging here, such as paranitrophenol, occur in an unstable and a stable modification, and the change of the former into the latter can be effected, but not the converse operation, and the change takes place at a temperature which is not definite. Each of the two modifications has its definite melting point, that of the unstable one being always the lower."[1]

An interesting instance of a fluid mass having its symmetry determined by the symmetry of a portion of the same mass already solidified is presented by the familiar fact that from a supersaturated solution of sodium ammonium racemate, the deposit of sodium-ammonium dextro tartrate is produced by contact with a crystal of this isomeride, while that of sodium ammonium laevo tartrate is brought about by the presence of a crystal of the latter sense.[2]

To compare with the conclusion that it is closest-packing which is concerned in the arrangement of the particles, we have the fact that in cases of polymorphism, greater stability is associated with greater density.[3]

Cleavage.

With regard to the question as to what will determine the direction of rupture of solidified assemblages, a little consideration shows *that a plane of readiest cleavage, i.e., a plane which is the locus of readiest separation, is not necessarily a plane the ties crossing which are ties of minimum strength under any given constant conditions.* For where *changes* of condition are taking place which affect parts of different nature differently, and cause a temporary or permanent re-arrangement of them, conditions of sudden strain of the ties which bind certain of the parts to one another may arise, and bring about a state of things such that the place of readiest rupture is

---

[1] O. Lehmann " Ueber physikalische Isomerie "; Zeitschr. f. Kryst., 1, p. 131.
[2] Compt. Rend. 63, p. 843.   [3] See Lehmann, Zeitschr. f. Kryst.. 1, p. 125.

the place of maximum temporary strain, and the latter will naturally be some plane which runs between nearest parts of *different* nature.

It seems therefore not improbable that planes of cleavage of the assemblages in question will be planes on the opposite sides of which contiguous parts which face one another are most diverse.

Polar properties.

All polar properties of homogeneous assemblages, such for example as would correspond to pyro-electric, or piezo-electric phenomena, since they depend on dissymmetry in opposite directions, will be impossible in all cases where centres of inversion are present, but may be looked for, to a greater or lesser extent, in all other cases. It does not appear that any peculiarity of form or arrangement of matter, other than that which is involved by the display of one or other of the possible types of homogeneity which are destitute of such centres, is necessary to account for any kind of mere opposite polarity.

II.—Partial dissolution in a symmetrical manner of the ties which hold the parts of a linked homogeneous assemblage in their places, and subsequent partial destruction of the homogeneity so that the assemblage breaks up into groups in each of which the parts are symmetrically placed with respect to one another, while the arrangement and orientation of the groups has become more or less irregular and fluctuating; the groups thus resembling the theoretical molecules of stereochemistry.[1]

Of the groups formed by linking together two or more balls

---

[1] Dr. Hantzsch defines Stereochemistry thus:—"Stereochemistry demands the single necessary supposition that the simplest group units, *i.e.*, the molecules, as well as all other complex groupings, have three dimensions. It requires, however, at least in its present stage of development, no definite concept as to the manner or origin of the holding together of the atoms within the molecule, *i.e.*, as to the nature of chemical affinity; nor as to the kind and origin of the combining proportions of the different atoms, *i.e.*, as to the nature of valency. At present it requires only the premiss, signally established by the existence of isomerism, that the atoms, as found within the molecule, are not in a chaotic condition, but are, within certain limits, arranged in stable

something has already been said.[1] We shall now consider the production of these groups by the simple means postulated at the outset of this inquiry, their nature and the effects of their presence.

1. As to their production :—

Suppose any homogeneous closest-packed assemblage of independent balls to pass uniformly into a partially tied state,[2] or, which will have the same result, suppose such an assemblage, after it has experienced a change to the solid state,[3] to pass partially, *but not completely* back into the unfettered state ; and suppose the change to take place *uniformly and symmetrically* throughout the assemblage. Some of the adjacent balls will now be linked together, and some will not, and it is manifest that the ties subsisting between those which are linked will exhibit a homogeneous[4] arrangement. For if anywhere two balls become linked, or cease to be linked, as the case may be, we shall have a similar change occurring in the case of every other similar set the individual balls of which are similarly related.

Granted then that the process is sufficiently uniform for the homogeneity of the assemblage, so long as no permanent movement takes place, to continue unimpaired, two or three distinct possibilities present themselves. Thus after the change has taken place the assemblage may consist of detached groups all of one kind, or of two or more different kinds, as just defined in the heading of this section, or it may consist of a single homogeneous network of linked balls, the meshes of which are occupied by balls which are not linked to one another, or to those forming the network.

Deferring the consideration of the last-mentioned contingency

---

equilibrium. The intermolecular movements which are undoubtedly present, can, as a rule, be neglected, for they can be supposed to be periodic about a centre of equilibrium. Thus, from a stereochemical standpoint, a molecule can, as a rule, be regarded as a statical system of material points whose dynamical properties only need to be taken into account under certain conditions, such as change of arrangement." (" Grundriss der Stereochemie," von A. Hantzsch, Breslau, 1893, p. 1). Comp. " Stéréochimie," par van 't Hoff et Meyerhoffer, Paris, 1892, p. 1. Also see *post,* note 1, p. 688.

[1] See pages 535 and 556, comp. pp. 609 *et seq.*
[2] See p. 530.   [3] See note 1, p. 530.
[4] Homogeneous according to the definition before referred to. See note 1, p. 531.

for the present,[1] and devoting our attention to the groups, we notice that the presence of a single detached group of any kind will involve the existence of a number of groups similar to it dispersed through space, and without going outside our data, we have, therefore, means for the manufacture of a number of groups of precisely the same pattern, such as we have already seen can be packed together in various ways.

An assemblage which by the rupture of some of the ties in a homogeneous manner has been partitioned into uniform groups, or groups of a limited number of kinds, may display as orderly an arrangement of its parts as prevailed before the ties were broken, but we can, on the other hand, conceive of it as disturbed by some external influence, so that the arrangement and orientation of the groups with respect to one another becomes more or less irregular. Yet, and this is important, *notwithstanding any disturbance from without, the interaction of its parts, to which the tendency to pack closely is traceable, may continually operate to diminish irregularity, and although the work done may be continually undone, may perpetually re-arrange the groups, ever striving after that orderly arrangement which gives the closest-packing possible.*

A pure chemical compound in a liquid state will evidently be comparable to an assemblage in which the ties have been symmetrically broken in such a way as to give but a single kind of group of linked spheres, the arrangement and orientation of the groups having simultaneously become more or less irregular.

2. As to the nature of the isolated groups, we may regard these as small similar fragments of a solid assemblage, mobile as to one another, but of stereotyped pattern. The component parts of such a group will be arranged with as high symmetry with respect to one another, as they displayed in the homogeneous assemblage in which the grouping was produced; in some cases they may display greater symmetry, namely, if the balls of a group, when the links connecting them with the balls of other groups are broken, are able to take up more symmetrical relative situations consistently with the variety of balls found in the group.

---

[1] See pp. 640, 676, and 679. The case whose consideration is thus deferred must not be confounded with the spongelike structure produced by intercalation subsequently suggested to be that of crystalloids, see p. 666.

The nature of the symmetry when all the balls composing a group are of the same kind has already been described for some simple cases.[1] For cases generally it suffices to say that any homogeneous finite partitioning of a homogeneous assemblage of balls will conceivably furnish possible groups. In order that the partitioning may not be arbitrarily incomplete, *i.e.*, that wherever it separates two balls which have a certain relative situation, it may similarly sever the balls of every similarly related set, the partitioning must, however, have as high a degree of symmetry as that possessed by the assemblage partitioned, *i.e.*, must be compatible with the coincidence movements (Deckbewegungen) of the latter;[2] it is imperative too that the partition walls do not intersect any ball centres. The partitioning may be such as to produce one, two, three or more kinds of groups. The symmetry of the groups may be higher or lower than the generic symmetry of the assemblage from which they are carved.

As the breaking of any link is, as we have said, accompanied by the breaking of all similar links, it is evident that each ball must occupy a situation with respect to the other balls of the same group different from that it occupies with respect to the balls of other groups. *Obedience to this rule is observed in the examples of partitioning into groups given below.*

If the distances separating unlinked centres are greater than the distances separating linked centres, it is evident that so far as these distances remain unaffected by the nature of the grouping, the smaller the groups the greater will be the degree of expansion of the assemblage.

Unit Groups.

If a homogeneous assemblage is composed of groups of one kind only, and contains no unaggregated balls, it is evident that each group must contain balls of all the different kinds present in the assemblage in the numerical proportions in which they occur. In such a group the kind or kinds of which there are fewest may be represented by a single ball, or by two or more balls according to the size of the groups.

---

[1] See pp. 535, 539 *et seq.* and also p. 556.
[2] Comp. Mineralogical Mag., vol. xi., p. 130 ; or Zeitschr. für Kryst, 27, p. 460.

The centre of a unit group is not necessarily the centre of a geometrical space-unit[1] of the assemblage in which it occurs;[2] it may be the centre of an aggregate consisting of two or more such units taken together. Some of its ball-centres may lie upon axes of rotation, and thus bear a similar relation to two or more of these units. The number of space-units which can be comprised in a unit-group is, however, very limited, for it is evident that in ascertaining the situations of the space-units composing such a group, *no coincidence movements* (Deckbewegungen) *of the assemblage are admissible which shift the centre point of the unit-group*, since these would not bring the group to coincidence (Deckung) with itself.[3]

The following are some possible simple ways in which unit-groups may be formed by partitioning homongeneous assemblages into units of one kind only, or conversely, in which similar unit-groups may be fitted together to form homogeneous assemblages:—

1. Groups similar to one another of the composition A B, *i. e.*, each composed of two different balls of given kinds, may form an assemblage of type 2.[4]

Thus in an assemblage consisting of a number of similar groups, each composed of two balls of different kinds, let the link uniting the two centres be of such a nature that when equilibrium is arrived at the distance separating the centres in a group is but little less than the distance separating dissimilar centres in adjacent groups. Further, let the relations between the balls be very nearly that prevailing in the assemblage of type $7a_1$, described on page 549.

The arrangement of the centres for closest-packing will then, very approximately, be that prevailing in the last-named assemblage, a slight departure from this arrangement being, however,

---

[1] A geometrical space-unit of a homogeneous structure is any continuous portion of space which encloses every kind of point or position from which it can be viewed or considered, and but one of each kind. Comp. "Zeitschrift für Krystallographie," 23, p. 37.

[2] Comp. Zeitschr. f. Kyrst. 23, pp. 37–38, and 59, Taf. ii., figs. 13, 16, 17, 18.

[3] The hypothesis that crystal molecules are large composite units made up of a great number of smaller units, *i.e.*, of chemical molecules, is not, therefore, consistent with the geometrical necessities of symmetrical partitioning.

[4] See Zeitschr. f. Kryst., 23, p. 10.

caused by the balls of the same group being drawn rather nearer together, much as they are in the assemblage of paired balls of type 5, described on page 538. The two balls of a group are not, however, necessarily placed similarly, as in the last-named case, although balls of one kind lie very nearly at the cube centres, those of the other kind very nearly at the cube angles of the space partitioning employed to generate the system.

The result will be an assemblage of type 2, displaying the symmetry of class 32 in Sohncke's list,[1] the positions of centres of both kinds being singular points lying on the trigonal axes, but the spaces between the different points on such an axis being not all equal but alternately equal.

It is clear that the existence of the links must be postulated in order to get the balls arranged, as suggested, in the symmetry of type 2, and therefore that we have not shown by the foregoing how such groups can be produced, but only how they can be arranged. Their production may be effected by the symmetrical breaking-up of complicated assemblages into simpler ones in an endless variety of ways.[2]

2. Groups similar to one another of the composition $A_4 B_4$ may form an assemblage of type 7b₁, and may be obtained from a certain assemblage of this type.

Thus if an assemblage consisting of two kinds of balls present in equal numbers arranged in the tetrahedral hemihedry of the cubic system described on page 550 have its adjacent balls all linked together, this assemblage can, by a symmetrical breaking of the links, be divided into identical grouplets, each consisting of a tetrahedrally arranged group of four larger balls, to which are linked four of the smaller balls, these also having a tetrahedral arrangement, and the two regular tetrahedra formed by joining the balls of each set being oppositely orientated. All the four balls of each kind are therefore similarly placed in the grouplet.

3. Groups similar to one another of the composition $A_6 B_6$ may form an assemblage of type 62a₁, and may be obtained from a certain assemblage of this type.

Thus if an assemblage consisting of two kinds of balls present

_____

[1] See Zeitschr. f. Kryst., 20, p. 467.   [2] See p. 682.

in equal numbers arranged in the holohedral monoclinic symmetry described on page 559 have its adjacent balls all linked together, this assemblage can, by a symmetrical breaking of the links compatible with the coincidence-movements (Deckbewegungen), be divided into identical grouplets, each consisting of an octahedrally-arranged group of six of the larger balls, to each of the opposite triangular ends of which is linked a triad of the smaller balls, thus making twelve balls, six of each kind, linked together in each grouplet. All the six balls of each kind are similarly placed in the grouplet.

A partitioning into grouplets composed of half the number of balls, *i. e.*, three of each kind, may equally well take place consistently with the coincidence-movements (Deckbewegungen).

4. Groups similar to one another of the composition AB_2 may form an assemblage of type $10a_1$, or one of type 52, and these groups may also be obtained from certain assemblages belonging to these types.

Thus, if an assemblage composed of two kinds of balls, present in the numerical proportions 1 : 2, arranged in the dodecahedral hemihedral symmetry described on page 552, have its adjacent balls all linked together, this assemblage can by a symmetrical breaking of the links be divided into identical grouplets of the composition AB_2, the two similar balls being similarly situated.

Again, an assemblage thus composed, with the trapezohedral tetartohedrism described on page 556, can also be divided into identical grouplets of the composition referred to.

5. Groups similar to one another of the composition A_2B_4 may form an assemblage of type $62a_1$.

Thus an assemblage composed of two kinds of balls present in the numerical proportions 1 : 2, arranged when closest-packed, according to type $25a_1$, as described on pages 553, 554, can, without much change of the conditions of equilibrium, have its parts so linked and allotted as to form groups consisting of two nearest large balls, about which are grouped rectangularly four smaller balls, the six centres of a group lying at the angles of a right octahedron derived from a rectangular parallelopiped, the larger ones at the vertices, and all the groups being similarly orientated. For the modification in the arrangement to be slight in such a

case, the distances between the centres of a group must be but little less than the corresponding distances between next centres of different groups. The modified assemblage which results will have angles slightly different from right angles, and will belong to type $62a_1$, so that it will display the symmetry of class 3 in Sohncke's list; the situations of the smaller balls will be singular points lying in planes of symmetry, but not all alike in the unbroken assemblage; those of the larger ones will be singular points on digonal axes and on planes of symmetry on the two sides of which the corresponding points are not directly opposite.

In all the above cases the situations of all centres of the same kind in a group are identical,[1] and consequently the ties which bind them are respectively similar and equivalent.[2] This, however, is evidently not always the case, for we know that balls of the same kind may be differently situated in a homogeneous structure, and the same may hold true in a group.

It has been concluded above that there are countless cases in which the principle of closest-packing, where balls of different kinds are used, is productive of symmetrical assemblages, some of them capable, some incapable of being partitioned into units of a single kind, without lowering the type of symmetry. And when assemblages capable of this symmetrical partitioning are taken, and by some change of the external conditions their balls are aggregated into groups of a single kind, the balls of a group being linked with one another but not with balls of surrounding groups, a further application of the same principle will intermix these assemblages with other balls or complexes of balls, that is provided the combination produces still closer packing.

---

[1] Not, however, in all cases identical considered with respect to the unbroken assemblage.

[2] Comp. theory of ring-formation in "Handbuch der Stereochemie," von Dr. C. A. Bischoff und Dr. Paul Walden, Frankfurt-a-M., 1894, p. 50.

The symmetry of arrangement of some of the groups here described, and of other groups constructed in a similar way, appears to be inconsistent with the diagrammatic linking together of atoms in a molecule ordinarily adopted, but it must be remembered that the basis of this graphic conception of links lies rather in a relation subsisting between the atom and the group in which it occurs than in one between the atom and individual atoms round about it. The graphic representations ordinarily employed may therefore very possibly express too much, and the method require some modification. See some remarks on valency made later, p. 681.

Further, the more complicated assemblages produced in this way can be subjected to symmetrical aggregation and partitioning, and still more complicated groups obtained in this way; or a number of smaller groups of new patterns can be had by symmetrically altering the linking. And then, by appropriate changes of the external conditions, assemblages thus arrived at can be conceived to be broken up, and the various kinds of groups massed by themselves, all in obedience to the principle of closest-packing.

In this way, by the action of closest-packing, with the aid of the additional hypothesis of symmetrical linking, very intricate results may be reached by a number of successive steps as the conditions change, and orderly complexity and highly specialized grouping, such as appeared at first sight impossible of attainment by any selective action of the principle referred to, is seen to be quite within the capacity of this agency for producing symmetry.

As already noticed, a slight change in the relation between the balls may cause closest-packing to be attained in a different homogeneous arrangement,[1] and it is possible that in some cases two or more kinds of balls may be so related as readily to form a variety of different groups with but comparatively slight changes of the general conditions.[2] Two kinds of balls may for example be so related as, under slightly different conditions, to form groups of all or most of the different kinds just referred to above, and also complex combinations of these groups.

We may compare with this the complex isomerism displayed by the hydrocarbons, which may perhaps, as just hinted, be traceable to a species of polymorphism.

It is important in this connection to distinguish between that kind of dimorphism or polymorphism which affects only the solid or completely-linked state, and dimorphism or polymorphism of the kind just referred to. In cases of the former the two forms become identical when they pass to the liquid condition, *i. e.*, they have the same grouping. In cases of the latter not only is the arrangement of the tranquil homogeneous assemblages different, but the grouping when they break up is different, although the constituents of the assemblages are the same.

---

[1] See p. 575.   [2] Compare p. 576.

3. As to the effects produced by the presence of linked groups.

We see that in most respects the groups will behave much as single unlinked balls would do—homogeneity and close packing will, as we have already concluded, frequently go together whether the balls of an assemblage are aggregated in groups or not.

The same balls may, it is evident, under the same external conditions, take up two or more different relative arrangements in seeking equilibrium if some of them are linked together to form groups, and the grouping is different in different cases; and this will apply whether the balls are all of one kind or not, and whether in the different cases the groups contain the same sets of balls or not.

Marked difference of behaviour of the same set of balls may be expected in different cases, especially when we compare a case in which few links subsist with a case where there are many. Thus it is evident that the presence of links between balls will commonly prevent them from packing as closely as they otherwise would do, and that the more they are interlinked, the less free they will be to accommodate themselves to their surroundings, and the more the closeness of the packing will be likely to be impaired. And when a number of assemblages having similarity of composition, but differing in the amount of linking which obtains in them, are compared, the differences in the degree of closeness of the packing which are thus occasioned may be revealed by differences in the susceptibility of the assemblage to some external influence.

To compare with this we may cite the following from Lothar Meyer :—" Experience has shown that the normal compounds always have a higher boiling point than those with side chains,[1] and that the boiling point of the latter falls as the number of side chains increases. In the case of bodies having a similar constitution, the addition of CH_2 raises the boiling point by from 18° to 22°."[2]

---

[1] If the resemblance here pointed out has any significance, it would seem to furnish some additional evidence as to the nature of these " side chains "—to show that they have some of the properties of the links referred to in the text.

[2] Lothar Meyer's " Grundzüge der theoretischen Chemie," p. 84; or Bedson and Williams' translation, p. 91.

Persistence of properties after change of state.

When an assemblage is broken up into groups by the breaking of the ties which keep the groups fixed in the same relative situations with respect to one another, disturbing movements may cause the equilibrium to fluctuate and produce a liquid state in which the groups move with respect to one another while the parts of the same group preserve the same constant arrangement.   *And when this is the case it is evident that any properties of the assemblage which are traceable to the arrangement of the parts in the groups and do not depend on anything outside them, will persist in the liquid state.*

This reminds us of some chemical compounds, such as terpene and camphor, which not only in the liquid state, but also in the state of gas preserve the power of rotating the plane of polarization, and that in its fullest intensity.[1]

Different kinds of assemblages may display common properties.

In complex assemblages extensive breaking down of links and rearrangement may be conceived to take place without destroying all the simple groupings, or in other words, when grouplets are once formed, whether they have been formed alone or in conjunction with other grouplets, one may conceive them to be capable of taking part in a succession of different combinations and entering into the composition of larger groups without the ties which link their parts together being broken or permanently disarranged. And the properties of assemblages of different kinds which contain groups of the same kind may be expected to be similar so far as they are conferred by these common groups.

We may compare with this the fact that the behaviour of chemical compounds is often such as to convey the impression that the changes which they undergo leave untouched some of the atom-groupings within them.   Thus the different alcohols all contain a hydroxyl group,[2] and all the substitution derivatives of benzene contain the 6-carbon-atom benzene nucleus.

---

[1] Ann. Scient. de l'Ecole Norm., Sup. 1, p. 1, and Bischoff's "Handbuch der Stereochemie," p. 142.   See *Ibid*, p. 141 as to persistence of the property in the amorphous state.   Comp. Zeitschr. f. Kryst., &c., 27, p. 475.

[2] Lothar Meyer's Grundzüge der Theoretischen Chemie, Leipzig, 1893, p. 80.

Enantiomorphously related groupings — resemblances to optical and other stereo-isomerism.

It is possible for the same balls *under the same general conditions* to be formed into groups in different ways.

1. Thus suppose that two similarly-constituted homogeneous assemblages of balls are enantiomorphous to one another and that they experience a similar change of state so that corresponding similar groups are formed in each, but that the groups in one are enantiomorphous to those formed in the other ; then suppose that disturbance from without breaks up all symmetry in both *except that of the arrangement of the parts in the groups.*

We then have two fluid assemblages in which all corresponding *mean* distances between the ball centres are identically the same in both, and to most tests the two assemblages will appear indistinguishable from one another, and indeed destitute of symmetry, but *since the arrangement of the balls in the groups is not identical but enantimorphous in the two assemblages, the latter will differ from one another in regard to any property which is affected by this difference of arrangement.*

The difference in the grouping of the balls in fluid assemblages thus related finds a parallel in the enantiomorphous difference in the grouping of the atoms in the molecule which Pasteur, van 't Hoff, le Bel, and others have concluded must, in some shape or other, be present to account for some cases of isomerism, *i. e.*, those cases in which the chemical and physical properties of two carbon compounds are entirely alike, with the single exception that they exercise an opposite, but otherwise similar influence on a ray of plane-polarized light. Thus Pasteur in 1860, refers to the case of dextro- and lævo-tartaric acid in the following way :—" Are the atoms of the dextro-tartaric acid grouped in such a manner as to follow the winding of a right-hand screw, or are they placed at the corners of an irregular tetrahedron, or is their disposition such as to exhibit some particular kind of unsymmetrical arrangement ? We

---

(Bedson and Williams' translation, p. 87). Compare this writer's similar observations respecting Carboxyl and other groupings, p. 83. (Bedson and Williams' translation, p. 89). See also below, p. 595.

are not in a position to answer these queries. It cannot, however, be doubted that a grouping of the atoms is present which displays an unsymmetrical arrangement not to be brought to coincidence. Further it is equally certain that the arrangement of the atoms of laevo-tartaric acid is precisely the inverse of this unsymmetrical arrangement." [1]

One very important support of the conclusion that the source of the property of rotation is found in some peculiar grouping of the parts of the molecule which affects its symmetry is found in the fundamental fact discovered by Pasteur that when the solution of a body is optically active it displays in the crystalline state non-coincident hemihedrism, as in the case of quartz, a relation between the sense of the hemihedrism and the sense of the rotating power being always present.[2]

It is consistent with our data to suppose that for a group of balls or complexes of balls to permanently present an enantiomorphous form, it must contain a sufficient variety of them to prevent the possibility of some slight modification in the arrangement taking place which would increase symmetry and make the arrangement identical with its own mirror-image; for where such a change is possible it will be likely to occur because it will almost certainly bring about closer packing.

To compare with this suggestion we have the facts that every

---

[1] Recherches sur la dissymétrie moléculaire des produits organiques naturels. Leçons de chemie professées en 1860. Paris 1861, p. 25.

Van't Hoff originally made the assumption that the four atoms or atom-complexes, found in combination with a carbon atom, are situated at the corners of a regular tetrahedron whose centre is occupied by the carbon atom. The precise parallel in this investigation to such an assumption is found in the particular arrangement of this nature possible for a group in which the four atoms are alike. Perhaps the facts which have been supposed to indicate the existence of the very specialized arrangement referred to may be found in most cases to agree equally well with a much more general hypothesis. Van't Hoff himself suggests a less-specialized one as an alternative to his hypothesis just referred to, and probably a further widening of the conception will yet take place. See Stéréochimie, Nouvelle edition de " Dix années dans l'histoire d'une théorie," par J. H. van 't Hoff redigée par Dr. W. Meyerhoffer, Paris, 1892, pp. 11 and 13. Compare *post*, p. 609.

[2] This rule is not proved to apply in all cases, but the absence of proof of the existence of hemihedrism in some solitary instances is merely negative evidence, and the proof requisite in one of these instances, to transfer the body from a holohedral class of symmetry to a hemihedral one, may at any moment be discovered.

body possessing optical rotatory power contains an asymmetric carbon atom,[1] and that the optical activity disappears with the disappearance of the asymmetric carbon atom.[2]

The same kind of enantiomorphous grouplet may enter into the composition of various larger groups of different kinds, and show its presence by its characteristic properties. And if the dissimilar parts of the compared groups are identical with their own mirror-images, and consequently all the enantiomorphous properties are traceable to the portion which is identical in the different groups, the enantiomorphous properties of the latter may be expected to be very much alike.

In connection with this we may recall the conclusion reached by Bouchardat that if the molecule of an optically active body when it enters into the composition of compounds is neither decomposed or modified, the derivatives, like the body itself, are found possessed of rotatory power.[3] This conclusion is verified in the case of amygdalinic acid obtained from amygdalin, and in the case of camphoric acid obtained from camphor.[4]

Transition from one to the other of two enantiomorphously similar groupings.

It is conceivable that considerable local disturbances may suffice to cause a fluctuation of the arrangement of a group without breaking the ties which bind its parts together, and thus that an asymmetric grouplet may continually be tossed from one to the other of two enantiomorphously-similar groupings which are closest-packed arrangements. The ultimate effect of this upon an assemblage originally consisting entirely of asymmetric groups of one

---

[1] That is to say a carbon atom, the atom or atom-complexes associated with which present a diversity which leads, when the atoms are located in the way above described (note 1, p. 594), to an enantiomorphous form, *i.e.*, the molecule or complex containing the carbon atom is of the formula *a b c d*.

[2] Stéréochimie par van't Hoff und Meyerhoffer, p. 28.

[3] Compt. Rend. 28, p. 319; Journal f. prakt. Chemie 47, p. 455; Annalen der Chemie 72, p. 168; Jahresb., 1849, p. 123.

[4] Compt. Rend., 19, 1174 and 28, p. 319.

When in cases of substitution, the direction and amount of optical rotation show persistence during the conversion, it gives a clue to the discovery which of the atoms are concerned in the rotation, *i.e.*, which of them have an enantiomorphous grouping. (Comp. "Hantzsch's Grundriss &c.," p. 53.)

kind only will evidently be that it will come to consist of a mixture of both forms in practically equal proportions.[1]

We may compare with this the fact that several optically active substances admit of transformation, within certain limits of temperature, into inactive mixtures or racemic combinations of the two isomers of opposite sense, the change being accompanied by loss of optical activity. Consequently one-half of the molecules must experience a change to the inverse configuration. The converse of the change referred to never takes place. Thus dextro-tartaric acid is converted into a mixture of inactive meso-tartaric and racemic acids by heating at 165°–170°; similarly optically active mandelic and aspartic acids become inactive at 180°. Loss of optical activity also occurs when active amylic alcohol is warmed with soda, or when active leucin or tyrosin is heated with baryta.[2]

The chemical and physical properties of the mixture composed of two enantiomorphously related isomers are those common to the latter, *i.e.*, all except some effects on enantiomorphous compounds and the effect on a ray of polarized light. The mixture here referred to is the disturbed or liquid mixture in which the groups have every variety of orientation. If comparison be made between the two enantiomorphously-related assemblages and the mixture of them in equal proportions when the disturbances have subsided so that the assemblages are homogeneous, supposing the mixture to become so, we have the following interesting fact :—

Any enantiomorphous generic symmetry characterizing assemblages of the unmixed groups must disappear in the homogeneous mixture, because its continuance would necessitate its presence in both kinds, which, although consistent with certain kinds of twinning, would not be consistent with the existence of a single continuous assemblage. Those influences which produce enantiomorphism in the unmixed assemblages will, therefore, in the mixture neutralize one another. At the same time influences which are similar, and not enantiomorphously related in both, will be likely, to some extent, to survive.

---

[1] Compare " Stéréochimie " par van 't Hoff und Meyerhoffer, p. 44.

[2] Hantzsch, "Grundriss der Stereochemie," p. 34. Comp. "Stéréochimie" par van 't Hoff und Meyerhoffer, pp. 41, 42. " Die Lagerung der Atome im Raume," 1894 ed., p. 30.

The salts of tartaric and racemic acids respectively generally contain different proportions of water of crystallization, so that their crystal forms are not comparable, and but few cases are known in which the racemic form of a substance crystallizes with the same proportion of solvent as its optically active components. One such case has, however, been described by Armstrong and Pope.[1] Three modifications of sobrerol may be obtained, *i.e.*, laevo-, dextro-, and para-sobrerols. The two active modifications have identical chemical properties, and crystallize in hemimorphic monosymmetric prisms; the crystals of these optical antipodes are consequently enantiomorphous. On crystallizing a mixture of equal weight of each, holohedral orthorhombic crystals of the racemic modification are obtained. A very intimate crystallographic relationship exists between the crystalline forms of the active and inactive substances, as will be seen from the axial ratios given below.

Active sobrerol (monosymmetric), $\left\{ \begin{array}{l} a : b : c = 2{\cdot}4113 : 1 : 0{\cdot}8531 \\ \quad (\beta = 83° 38') \end{array} \right.$

Inactive sobrerol (Orthorhombic), $\left\{ \begin{array}{l} a : b : c = 2{\cdot}4242 : 1 : 0{\cdot}8268 \\ \quad (\beta = 90°)[2] \end{array} \right.$

Again, suppose :—

2. *That a homogeneous assemblage contains several different kinds of grouping of its balls which are not identical with their own mirror-images, and that the various symmetrical groupings are separated by tracts or films of balls so constituted as to be identical with their own mirror-image.*

When this is the case, it is possible for the same balls to form other homogeneous assemblages which, together with the given assemblage, are all connected by the property that *all corresponding distances between nearest centres are identical throughout the series of assemblages.* For, if in any such assemblage any one of these asymmetrical groupings is removed, and a similar complex enantiomorphous to it substituted and similarly placed, no alteration in the distances separating nearest centres, when these distances are taken collectively, will be thereby made. And, therefore, a

[1] Journ. Chemical Soc., 1891, p. 315.

[2] Quoted from Pope's translation of Fock's " Chemical Crystallography," p. 150.

number of enantiomorphous pairs of grouplets (A^r, A^l; B^r, B^l; C^r, C^l, for instance) may be placed, one of each pair, in the same symmetrical framework of balls to form as many assemblages thus related as there are possible combinations of the grouplets (eight in the case instanced, viz. A^r, B^r, C^r; A^r, B^r, C^l; A^r, B^l, C^r; A^r, B^l, C^l; A^l, B^r, C^r; A^l, B^r, C^l; A^l, B^l, C^r; A^l, B^l, C^l). The arrangement of the framework composed of balls which occupy the same relative situations in all the assemblages is, as we have said, identical with its own mirror-image.

When homogeneous assemblages thus related have their symmetry partly broken in a similar manner into units of a single kind without destroying the asymmetry of the grouplets,[1] the fluid assemblages which result will not all resemble one another in a similar manner. Any two which before the disturbance form a pair of strict enantiomorphs will resemble one another much more closely than two which are not so related, although the latter will also have very much in common.[2] And since the links are broken in such a way that the unit groups found after the assemblage has been disturbed are all of one kind, and there are no loose balls, the fluid assemblages produced will not be decomposed, and as many kinds will be presented as occur in the undisturbed state.

Although in the undisturbed state all corresponding distances between *nearest* centres are identical throughout the series of assemblages, the distances between centres slightly more removed from one another will not be thus identical in the case of two assemblages which are not strict enantiomorphs, and in which the asymmetrical grouplets are near together. Consequently the fluid assemblages derived from two such assemblages may be expected to show some difference in stability.

If the asymmetrical grouplets contained in a composite group are not all of different kinds, it is evident that the number of possible combinations will be diminished owing to some of those above symbolized becoming identical.

The facts and conclusions of stereo-chemistry are, to a great

---

[1] Comp. *ante*, p. 593.

[2] See "Grundriss der Stereochemie," p. 5. Comp. van 't Hoff und Meyerhoffer's "Stéréochimie," pp. 8 and 14.

extent, parallel to the variety of arrangement for the same balls *in closest-packing* thus shown to be possible when several different grouplets not identical with their own mirror-image are present. Thus Hantzsch, says[1] :—" Bodies having two asymmetrical carbon atoms of the general formula *Cabc, Cdef*, possess the component rotations *A* and *B*, which can either of them be present in the positive or the negative configuration. Thus four combinations, and corresponding to these four optical isomers, are possible corresponding to the expressions —

1. $+A$ 2. $+A$ 3. $-A$ 4. $-A$
    $+B$ $-B$ $+B$ $-B$

Of these the first and fourth, and also the second and third have opposite and similar specific rotations, and thus correspond to compounds which show mirror-image isomerism. Consequently the first and fourth, and also the second and third, can together form inactive mixtures, but not so the first or the fourth in combination with either the second or third. Similarly, bodies with three asymmetrical carbon atoms of the structure formula *Cabc*, *Cde, Cfgh*, if they possess three component rotations indicated by *A*, *B*, *C*, are possible in $2^3 = 8$ isomerides.

These conclusions are in a very striking manner borne out by facts. For example, when camphor is converted into borneol two isomerides, a dextro stable, and a laevo labile modification are produced, and these can be separated from one another by simple crystallization; they both furnish on oxidation the same original camphor. The laevo-camphor, in its turn, in the same way furnishes means for the forming two complementary compounds, as appears in the following table :—

Dextro-camphor,	}	Right-stable borneol.
		Left-labile ,,
Lævo-camphor,	}	Left-stable ,,
		Right-labile[2] ,,

A difference of stability, and of some other properties such as,

---

[1] " Grundriss der Stereochemie," p. 18.

[2] " Stéréochimie " par van 't Hoff u. Meyerhoffer, p. 54. Comp. Bischoff's " Handbuch der Stereochemie," p. 359. And also comp. " Stéréochimie," p. 57, as to Zincke's observation respecting the glycols. Also " Hantzsch's Grundriss &c.," p. 42.

according to what has just been said above, we should look for in assemblages related in the way described, is actually presented when there are several isomers. We thus find isomers distinguished as *stable* and *labile*, and presenting physical and, to a slight extent, chemical differences.[1]

We find, too, that the process of change under change of conditions, such as rise of temperature, is complicated by the greater variety possible where there are more than two isomers enantiomorphous to one another. Thus van 't Hoff says :—" As shown on page 41, compounds containing a single asymmetrical carbon atom when heated yield an inactive mixture corresponding to the stable equilibrium described. Compounds having two or more asymmetrical atoms show a different behaviour. It is manifest that in this case also the inactive mixture corresponds to the equilibrium which is finally arrived at, but two steps are generally requisite to reach this ultimate goal, for in general one of the two or more atoms accomplishes the transformation more quickly, and consequently under conditions which leave the rest yet unaltered. Starting, therefore, from the compound $+ A + B$ we obtain at first a mixture of $+ A + B$, and $+ A - B$. And taking into consideration that the quantities of the two products formed at the end of the first phase are by no means the same—indeed the two molecules, which are not as to their structure mirror-images of one another, will in general manifest a different degree of stability— we shall not be surprised to find that in the case of the transformation in question almost the entire mass comes to consist at first of $+ A - B$; it may be with the reversal of the sense of the optical rotation. This result has in fact been observed."[2]

Racemic mixtures [3] of those isomerides which are strict enantiomorphs, that is to say,

$$(+ A + B) \quad \text{with} \quad (- A - B)$$
$$\text{and} \quad (+ A - B) \quad \text{with} \quad (- A + B)$$

---
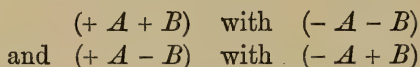
[1] " Grundriss der Stereochemie," pp. 5, 37, 43. " Stéréochimie " par van 't Hoff, &c., pp. 50, 53 *et esq.*

[2] " Stéréochimie," par van 't Hoff und Meyerhoffer, p. 57. Comp. Pasteur's words respecting the changes of quinine derivatives in Compt. Rend., xxxvii., p. 110.

[3] See pp. 596, 603.

have been synthetically obtained in the case of the borneols, phenylurethanes and the camphoric acids.[1]

As to the diminution, just now referred to, of the number of possible combinations when the asymmetrical grouplets contained in a composite group are not all of different kinds, we may compare the facts cited by van 't Hoff and others,[2] and especially that as to the production of the *inactive indivisible type* of the composition $(A + B) + (- A - B)$ or $(A - B) + (- A + B)$, the inactivity arising from the intramolecular compensation, and being distinct from the inactivity produced by mixing enantiomorphous molecules.[3]

The most familiar example is furnished by the isomerism of the tartaric acids. Thus in this group we find the two isomers with similar opposite rotation, also their inactive mixture, racemic acid, which was separated into its two constituents by Pasteur. But what in particular distinguishes the case in question is the existence of an *indivisible inactive* isomeride,[4] which was also discovered by Pasteur, and which Przibytek[5] some time ago in vain sought to divide.

Several compounds may besides be mentioned whose constitution approximates more to the tartaric acids in so far as they, like the latter, are distinguished by a symmetrical formula and two asymmetrical atoms. These bodies deserve particular attention because they always furnish a case of isomerism which, according to the old views, is inexplicable. Most of these compounds have only recently been investigated, principally by Bischoff.[6]

The packing of a given asymmetric grouping will, in some cases, be closer when one of the two kinds of enantiomorphs alone is

---

[1] "Stéréochimie" par van 't Hoff u. Meyerhoffer, p. 56; and as to less symmetrical mixtures, p. 57, *et seq.* Comp. "Grundriss &c.," p. 39, *et seq.*

[2] "Stéréochimie" par van 't Hoff, &c., p. 61.

[3] Comp. Hantzsch, "Grundriss &c.," pp. 20, 26, and 45.

[4] As Hantzsch remarks:—"In the two dextro and laevo tartaric acids the two asymmetrical complexes – CH(OH) COOH must have configurations of the same sense, but in the inactive indivisible tartaric acid one of them must have the opposite sense to that of the other. (See "Grundriss &c.," p. 44.)

[5] Berl. Ber., xvii., 1412.

[6] "Stéréochimie," par van 't Hoff, &c., p. 63. Comp. "Lagerung der Atome im Raume," 1894 ed., p. 33, and Hantzsch's "Grundriss &c.," pp. 24 and 26.

present in the assemblage; in other cases it will be closer if both are present.

To give two simple illustrations.

If a number of similar groups have their outside ball-centres so arranged as to form either regular 12-point groups or 24-point groups,[1] and we form a close-packed homogeneous assemblage in which the centre-points of the groups lie at the centres of a number of cubes filling space, the groups will fit into one another better if they are all identical than they will if some are of one hand, some of the other hand.

If, however, we form a close-packed homogeneous assemblage by placing groups whose outside ball-centres form 24-point groups, with their centres at the centres and angles of the cubes of the space-partitioning, the packing will be closer when half of the groups are of one hand, half of the other hand symmetrically distributed, than it will be if all are identical.

We see, therefore, that the principle of closest-packing will in some cases, under some conditions, make assemblages which are composed of similar groups of two enantiomorphous kinds split up to form separate assemblages of each kind of group, while under other conditions it will cause the two enantiomorphous kinds to intermix when two assemblages each consisting of one kind alone are brought in contact. And both effects may come about in a great variety of ways, and with almost all conceivable kinds of asymmetric groupings, and the same assemblage may under one set of conditions display the one effect, and under another set of conditions display the other effect.

Further, one or the other of these effects will often be presented when more than one kind of group is present, and, indeed, it is conceivable that the presence of an additional kind of ball or complex of balls in an assemblage may cause it to exhibit one of the properties referred to instead of the other.

The effects just mentioned are exactly paralleled in the behaviour of some chemical compounds. Thus, van 't Hoff says :—
" The separation of the two isomers, endowed with rotation-proper-

---

[1] See Sohncke's "Entwickelung einer Theorie &c.," pp. 156 and 166, or Zeitschr. für Kryst. 27, p. 451. To produce the most striking effect the ball-centres should lie well away from the symmetry-planes of the system of axes.

ties of opposite sense, present in an optically inactive mixture composed of the two, constitutes one of the most difficult of problems, the isomers presenting as they do, the completest identity of their chemical attributes. Racemic acid, which we can with certainty regard as a mixture of the two active tartaric acids, furnishes with sodium and ammonium a salt of the formula $C_4H_4O_6NaNH_4$. This salt can be obtained in crystals of a rhombic form which display the hemihedral modification, and as a result allow the recognition of enantiormorphism. Now it has been found that the solution of the crystals of one sort brings about a right-handed rotation of the plane of polarization, while that of the other sort, enantiomorphous to them, brings about a left-handed one. The acids separated from the two sorts of crystals behave themselves in a similar manner, the one proving to be identical with dextro-tartaric acid, the other with laevo-tartaric acid. Thus the crystallization of the double salt referred to effects the separation of the optically inactive racemic acid into its components, the two active tartaric acids."[1]

Such a separation by means of crystallization is, however, one of the rarest occurrences.[2] On the contrary, the separation of the optically-opposite components of an inactive mixture appears to be rendered more difficult by the circumstance that the molecules which are oppositely endowed as to their optical activity, display a certain mutual readiness to combine.

Racemic acids and other compounds whose enantiomorphous isomers display this readiness to combine are known as racemic forms. Hantzsch speaks of them as follows:—" The inactive forms thus obtained have sometimes been regarded not as mere mixtures but as definite, although unstable compounds, of two mirror-image molecules. This kind of combination was first observed in the case of racemic acid = acide racémique, and has therefore been designated racemation."

He further remarks:—" The formation and continuance of a

[1] Van't Hoff's " Lagerung der Atome im Raume," 1877 ed., p. 41. Comp. 1894 ed. of same work, p. 23. Comp. " Grundriss &c.," pp. 31 and 32 ; also " Stéréochimie " par van't Hoff and Meyerhoffer, p. 73.

[2] Die " Lagerung der Atome im Raume" 1894 ed., p. 24. Compare " Grundriss der Stereochemie," pp. 31 and 32.

racemic compound is associated with a certain temperature limit, and this is also the case in the solid condition. Thus, for example, it is only above 28°, the temperature of interconversion, that the racemate is formed from dextro- and laevo-sodium ammonium tartrate; while at temperatures below this the converse process takes place. Racemic combinations behave in this respect therefore like salts which contain water of crystallization and particularly resemble double salts in their relation to the two components, in that both production and separation of the tie are connected with certain definite conditions of temperature."[1]

We may further quote from van 't Hoff as showing how necessary for chemical action it is that the configurations of the groups which come together shall be adapted to one another. " The chemical identity of the two active tartaric acids, which is manifested in every case of their combination with an optically-inactive substance, ceases to show itself directly optically-active substances take part in the reaction. Thus, for example, the acid ammonium salt of dextro-tartaric acid combines with the acid ammonium salt of laevo-malic acid to form a readily crystallizing double salt, whilst on the other hand the acid ammonium salt of the laevo-tartaric acid will not enter into combination with the acid ammonium salt of laevo-malic acid. Dextro-tartaric acid combines with laevo-asparagine to form a crystalline salt, but laevo-tartaric acid will not combine with asparagin ; and other examples can be called to mind."[2]

The formation of groups in the way indicated above,[3] admits of very wide application, and if there is some considerable variation of the conditions, we shall expect frequently, even where no asymmetry is present, to encounter some variety in the kind of group produced from a given set of balls. Variety thus produced which does not spring from any enantiomorphous relations, will, however, be very much of the nature of the polymorphism previously treated of,[4] and we may expect the properties of the different groups formed of the same set of balls to differ greatly, indeed in some cases almost as much as those of groups of different sets.

---

[1] " Grundriss der Stereochemie," pp. 32, 33.

[2] Van 't Hoff, " Lagerung der Atome im Raume," 1877 ed., p. 42.

[3]   [4]

Groups of identical composition which differ very greatly may generally be compared with the structure-isomerides of the chemist, but, as we shall notice immediately, cases are conceivable in which, while no enantiomorphous relations subsist, some considerable degree of resemblance exists between the different kinds of grouping of the same set of balls, and which therefore have a more intimate connection than appears to subsist in cases of mere structure-isomerism.

In this connection an attempt at classification of isomers made by Hantzsch may be referred to. He says:—

"It is difficult to characterize stereo-isomerides in a general manner; in attempting to do so we must substantially confine ourselves to the following :—

Stereoisomerides as distinguished from structure-isomerides are generally more readily and mutually capable of transformation one to the other. According to their behaviour they fall into the two following groups :—

1. *Substances displaying identity of all actual properties and differing only with regard to their action on polarized light, their "optical activity,"* called therefore optical or mirror-image isomerides. These are substances whose atoms are at the same absolute distances apart in the molecule, but have a different order as to their arrangement; they may perhaps be named "relative stereoisomerides." According to theory *such substances contain asymmetric atom complexes.*[1] Isomerides of this kind which contain but one asymmetric atom-complex are, with the single exception of their optical behaviour, absolutely identical. Those with several asymmetric complexes may besides exhibit differences in their physical, and even to some slight degree in their chemical behaviour.[2]

2. Substances which in spite of the identity of their structural formula and the behaviour thereby expressed, nevertheless *exhibit differences in all physical and in certain chemical properties not to be expressed by structural formulæ, but are without action on polarized light.*"[3]

---

[1] See *ante*, pp. 594 and 595.   [2] Compare p. 598.

[3] Hantzsch's " Grundriss der Stereochemie," pp. 5 and 64. Compare Bischoff's " Handbuch der Stereochemie," p. 46.

Now, as has just been said, important likenesses between different kinds of grouping of the same set of balls are conceivable, even where no enantiomorphous relations subsist, these likenesses being comparable to the resemblances which Hantzsch would place under his heading II. Thus suppose that the same homogeneous assemblage of balls, having the same arrangement, is symmetrically partitioned[1] in two different ways into group-units of the same composition by appropriate breaking of some of the links, the *external* balls of one kind of group being *internal* balls of the other kind of similarly-constituted group. It is then evident that the properties of two liquid assemblages thus obtained may be widely different in many respects, and that at the same time one kind of assemblage may readily by a change of conditions be transformed into the other. And the same will be true of two assemblages which are thus related which have in the solid state not precisely the same arrangement, but only approximately the same.

It is further quite conceivable that the addition of certain balls in a homogeneous manner to one of the two assemblages may cause a change in the partitioning, *i. e.*, in the system of linking, which will convert it into an assemblage allied to the other of such assemblages.

With this conclusion we may compare the fact that while bromomaleic acid is produced from fumaric acid and bromine, bromofumaric acid is produced from maleic acid and bromine, fumaric acid and maleic acid being isomerides.[2] This kind of change is however, considered later.[3]

It is not difficult to perceive that homogeneous assemblages composed of spheres of different sizes packed as close as possible will generally have fewer points of contact when the symmetry is enantiomorphous than when the assemblages are identical with their own mirror-images, and consequently that the packing will generally be closer in the latter case ; further, we see that *where the closest packing possible under certain given conditions is very compact, it is less likely that some alternative arrangement will, when a slight change of conditions occurs, be found to be the closest*, in other

---

[1] See p. 585.

[2] " Grundriss der Stereochemie," p. 77.   Comp. Holt, " Berl. Ber.," 24, p. 4129.

[3] See below, p. 685.

words less likely, that dimorphous arrangements productive of isomerism will be presented.

Perhaps chemical saturation is akin to closeness of packing,[1] and if so, we may, for comparison with the conclusion just stated, cite the fact that no stereochemical situation-isomerism has hitherto been detected in saturated compounds of identical structure, from which it would appear that under given conditions but one single equilibrium position is capable of a lasting existence.[2]

That the stereoisomerism of unsaturated compounds has identity substituted for it in the corresponding saturated compounds is illustrated by the experimental fact that with the greatest precautions one and the same succinic acid is obtained by the reduction of fumaric acid and maleic acid alike.[3]

Before bringing to an end these observations on the effects produced by the presence of groups, a few more words should be said about resemblances existing between groups composed of different sets of balls.[4]

Groups which are differently arranged may, whether their composition is the same or not, bear a partial resemblance which causes some similarity of behaviour.

As a case in point we may take that of *groups whose resemblance consists in their having the same kind or kinds of balls outermost.* For one of the effects of a given kind of ball or set of balls lying outermost in a group will manifestly be that the balls thus situated will be more exposed to separation from the group and recombination of a different kind than if their place were in the interior, and groups resembling one another in the way referred to will, therefore, have some properties in common.

With this may perhaps be compared the suggestion that the separation of water in the case of dibasic acids, such as phthalic acid and maleic acid, is associated with near proximity of the hydroxyl groups.[5]

---

[1] See page 680.   [2] Hantzsch's "Grundriss der Stereochemie," p. 61.

[3] *Ibid.*, p. 90.

[4] A general conclusion respecting groups of slightly different composition which have a certain resemblance has already been stated. See p. 591.

[5] Compare Bischoff in Berl. Ber., xxiii., p. 620, and in "Handbuch der Stereochemie," p. 113 ; also Hantzsch's "Grundriss der Stereochemie," pp. 67 and 101.

Groups which resemble one another as to parts of them which are identical. Comparison with some cyclic and non-cyclic combinations.

There is a way in which groups which are not isomerides may be closely related, where the resemblance does not spring solely from an enantiomorphous relation, while, at the same time, such a relation is not excluded. Thus, instead of obtaining a number of different groups by changing the grouping of a given set of balls, we may fix upon some particular arrangement for a group, and then derive a series of related groups from it by substituting for one or more of its balls other different balls or complexes of balls, leaving the relative situation in the group of the remaining balls unaltered,[1] and waiving the question of the arrangement of the groups in the different assemblages. Groups obtained in this way will resemble one another as to all properties imparted solely by the identical portions common to them, but, in addition to this we have the interesting fact that under some conditions the *number* of different groups obtainable from a given group by a specified number of substitutions can be ascertained. For, if the general conditions are constant, or which amounts to the same thing, if we disregard any change of arrangement brought about by changes in these conditions, it is evident :

1. That the substitution for a particular ball in each group of a certain different ball or rigid complex will modify the conditions of equilibrium of an assemblage of similar groups *in a definite manner* determined by the action of the fundamental law of closest-packing, so that the position of the substituted ball or complex with respect to the remainder of the group may be regarded as fixed, and this will still apply if the substituted ball becomes attached to its group.

2. That when two or more of the same sort of original balls are exchanged for others, and *some of the balls left resemble those removed both in their nature and their situation*, the exchange may be effected in a definite number of different ways depending on the nature of the grouping, the number of balls removed, and the number remaining which are similar to them.

---

[1] We are not, for the moment, concerned as to whether this change can be made without travelling outside our data ; some suggestions as to this are, however, made later. See p. 673.

Now the variety of types of grouping possible in which some given number of *similar* balls can be grouped about a centre *in similar situations* in such a manner that the group is competent to form part of a homogeneous assemblage, is not very large, and the number of different ways in which a certain number of similar balls of any particular group of this nature can be exchanged for other balls or complexes differing from them is easily ascertainable.

The following is a short enumeration of all the types of grouping of similar balls possible, and it is accompanied by a statement of the number of different types obtainable by twofold[1] substitution, *i. e.*, of the number of different groups derivable by the exchange of *two* of the original similar similarly-placed balls for other balls or complexes different from them. In enumerating the groupings not only types in which the similar balls occupy identical situations are given, but also those in which the situations are of two kinds enantiomorphously similar. The number of groups derivable in any case by the substitution of different balls or complexes depends not only on the arrangement of the balls some of which are removed, but also on the arrangement of other balls forming part of the same group, if any such are present.[2]

It will be convenient to refer to the diagrams in Sohncke's list of Krystallklassen contained in Zeitschr. für Kryst., xx., p. 457.

In every case in which the similar balls occupy *identical* situations in the group, it is manifest that, whatever the number or arrangement of these balls, substitution *for one only* will produce identically the same effect whichever of the similar balls is selected for removal. In cases, however, where the situations are of two kinds enantiomorphously similar to one another, single substitution of the same ball or complex can be made in two ways, resulting in two different groups which are enantiomorphs.

1. As to the number of different types of groups existing in which *two* balls are similarly situated, we see that two *identical* situations without other similar ones, can be found in groups of either one of the classes 3, 5, 6, 7, 8, 9, 10, 12, 13, 15, 21, 22, or 24 in Sohncke's list just referred to, the required centres being

---

[1] Threefold, fourfold, &c., substitution are also readily traceable, but the results would consume too much space here.

[2] Compare Bischoff's " Handbuch der Stereochemie," § 3, p. 635.

singular points,[1] *i. e.*, lying in axes, or in planes of symmetry, or in both of these, except in the case of class 5. Groups belonging to classes 5, 7, 10, 15 or 22 are not identical with their own mirror-images, and consequently exist in two enantiomophous forms.

If the situations of the two balls are enantiomorphously similar they may be found in any group whose symmetry is that of either of the classes 1, 3, 4, 11, 14, 16, 23, or 25.

Twofold substitution in a group of either of these two sets, if the two balls or complexes substituted are both of the same kind, can, it is evident, be made in one way only. And if the two balls substituted are of two different kinds, *and the situations of the original balls are identical*, such substitution can still be made in only one way.

If, however, the situations of the original balls are only enantiomorphously similar, as in the classes last mentioned, and the two balls substituted are of two different kinds, *two* different groups are obtainable from the original group, and these are enantiomorphs.

2. If a group contains *three* similar balls similarly placed, and no others occupying similar situations, it is evident that they must lie at the angles of an equilateral triangle, and that the number being odd, the existence of enantiomorphously similar situations for any of the three balls is precluded.

And three identical situations, without other similar ones, can be found in groups of either one of the classes 13, 15, 16, 19, or 20 in Sohncke's list, the required positions for the centres being singular points except in the case of class 20. Groups belonging to classes 15 or 20 are not identical with their own mirror-images, consequently exist in two enantiomorphous forms.

Twofold substitution in any such group containing three balls can be carried out in one way only when the substituted balls are both of the same kind. When they are of two different kinds the same is true in the cases of groups of classes 13 or 15, but two different groups are obtainable where the original group is of class 16, class 19 or class 20, and these two derived groups are enantiomorphs when the group from which they are derived belongs to class 19.

---

[1] Compare Zeitschr. f. Kryst., 23, p. 60.

3. A group containing four similar balls similarly placed will, if the situations of the four balls are *identical*, belong to one of the classes 6, 7, 21, 22, 23, 24, 26, 27, 30, or 32. If the similar situations of the four ball-centres form two sets of two points enantiomorphously related, it will belong to one of the classes 3, 8, 24, or 25. In all cases, except when the group belongs to class 3, 7, 8, 25 or 27, the situations of the ball-centres will be singular points. Groups of classes 7, 22, 27 or 32 are not identical with their own mirror-images, consequently exist in two enantiomorphous forms.

The number of different groups which can be derived by twofold substitution, *i.e.*, by substituting two balls or complexes for some two of the four similar balls found in a group, is given below in two columns A and B, A giving the number obtainable when both substituted balls are alike, B the number when they are different from one another. If any of the derived groups are enantiomorphs the number of these is given. Those which do not pair as enantiomorphs are identical with their own mirror-images, *except in cases where the original group is itself an enantiomorph.*

Description of group of similar similarly situated ball-centres before substitution is made.	NUMBER OF GROUPS DERIVABLE.			
	A.		B.	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Four-Ball Groups.				
4*a*, Class 6, the four similar ball-centres lie at the angles of a rectangle, .	3	—	3	—
4*b*, Class 7, at either set of the alternate corners of a rectangular parallelopiped (an enantiomorph), ...	3	—	3	—
4*c*, Class 21, at the angles of a square, .	2	—	2	—
4*d*, Class 22, at the angles of a square (an enantiomorph), ...	2	—	2	—
4*e*, Class 23, at the angles of a square (an enantiomorph), ...	2	—	3	—

Description of group of similar similarly situated ball-centres before substitution is made.	NUMBER OF GROUPS DERIVABLE.			
	A.		B.	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Four-Ball Groups—*continued.*				
4*f*, Class 24, at the corners of a right tetrahedron,[1]	3	1 pair	3	1 pair
4*g*, Class 26, at the angles of a square .	2	—	3	1 pair
4*h*, Class 27, at the angles of a square (an enantiomorph), ...	2	—	3	—
4*i*, Class 30, at the corners of a regular tetrahedron, ...	1	—	1	—
4*j*, Class 32, at the corners of a regular tetrahedron (an enantiomorph), .	1	—	1	—
4*k*, Class 3, at the angles of a rectangle, .	4	1 pair	6	3 pairs
4*l*, Class 8, at the angles of a rectangle, .	4	1 pair	6	3 pairs
4*m*, Class 24, at the angles of a square,[2] .	3	1 pair	4	2 pairs
4*n*, Class 25, at the corners of a right tetrahedron,[3]	4	1 pair	6	3 pairs

4. A group containing six similar balls similarly placed will, if the situations of the 6 balls are *identical,* belong to one of the classes 9, 10, 11, 12, 13, 15, 17, 18, 28, 29, 30, 31 or 32 in Sohncke's list. If the similar situations of the six balls *form two sets enantiomorphously related,* it will belong to one of the classes 12, 14, 16, or 19. In all cases, except where the group belongs to class 14, 15, 16, 18, or 19, the situations of the centres will be singular points. Groups of classes 10, 15, 18, 29, or 32 are not identical with their own mirror-images, consequently exist in two enantiomorphous forms.

---

[1] The ball-centres lie in the planes of symmetry. The tetrahedron is *not regular.*
[2] The ball-centres lie in digonal axes.
[3] Not a regular tetrahedron.

The number of different groups obtainable by twofold substitution given under the two heads A and B as before, is as under :—

Description of group of similar similarly situated ball-centres before substitution is made.	NUMBER OF GROUPS DERIVABLE.			
	A		B	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Six-Ball Groups.				
6a, Class 9, the six similar ball centres lie at the angles of a regular hexagon, .	3	—	3	—
6b, Class 10, the six similar ball centres lie at the angles of a regular hexagon (an enantiomorph), ...	3	—	3	—
6c, Class 11, the six similar ball centres lie at the angles of a regular hexagon, .	3	—	5	—
6d, Class 12, at the alternate corners of a right regular hexagonal prism,[1] .	4	1 pair	5	2 pairs
6e, Class 13, at the corners of a triangular right prism, ...	4	1 pair	5	2 pairs
6f, also Class 13, two and two in the sides of an equilateral triangle equidistant from the angles, ...	4	—	5	—
6g, Class 15, form a trigonal 6-point-group which has no plane of symmetry (an enantiomorph), ...	4	—	5	—
6h, Class 17, at the angles of a regular hexagon, ...	3	—	5	2 pairs
6i, Class 18, at the angles of a regular hexagon (an enantiomorph), . .	3	—	5	—
6j, Class 28, at the corners of a regular octahedron, ...	2	—	2	—
6k, Class 29, at the corners of a regular octahedron (an enantiomorph), .	2	—	2	—
6l, Class 30, at the corners of a regular octahedron, ...	2	—	3	1 pair
6m, Class 31, at the corners of a regular octahedron, . . , . .	2	—	3	—
6n, Class 32, at the corners of a regular octahedron (an enantiomorph), .	2	—	3	—
6p, Class 12, at the angles of a regular hexagon,[2]	4	1 pair	6	3 pairs
6q, Class 14, at alternate angles of a regular right-hexagonal prism, . . .	5	2 pairs	10	5 pairs
6r, Class 16, at the corners of a triangular prism.	5	2 pairs	10	5 pairs
6s, Class 19, two and two in the sides of an equilateral triangle equidistant from the angles, ...	5	1 pair	10	5 pairs

[1] The centres lie in planes of symmetry.

[2] The centres lie on digonal axes.

5. A group containing eight similar balls similarly placed will, if the situations of the eight balls are *identical*, belong to one of the classes 21, 22, 28, or 29. If the similar situations of the balls *form two sets enantiomorphously related* it will belong to one of the classes 6, 23, 24, 26, or 31. In all cases, except when the group belongs to class 6, 22, 23, 24, or 26, the situations of the ball-centres will be singular points. Groups of classes 22 or 29 are not identical with their own mirror-images, consequently exist in two enantiomorphous forms.

The number of groups obtainable by *twofold* substitution given under two heads A and B as before, is as under:—

Description of group of similar similarly situated ball-centres before substitution is made.	NUMBER OF GROUPS DERIVABLE.			
	A		B	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Eight-Ball Groups.				
8a, Class 21, the eight similar ball-centres lie at the corners of a right square prism,	6	1 pair	7	2 pairs
8b, also Classes 21, on the four sides of a square equidistant from the angles, .	6	—	7	—
8c, Class 22, form an 8-point-group without planes of symmetry (an enantiomorph)	6	—	7	—
8d, Class 28, at the corners of a cube, .	3	—	3	—
8e, Class 29, at the corners of a cube (an enantiomorph),	3	—	3	—
8f, Class 6, at the corners of a rectangular parallelopiped, ...	10	3 pairs	14	7 pairs
8g, Class 23, at the corners of a square prism,	8	3 pairs	14	7 pairs
8h, Class 24 (for form see Sohncke's fig.), .	10	4 pairs	14	7 pairs
8i, Class 26, on the four sides of a square equidistant from the angles, . .	8	2 pairs	14	7 pairs
8j, Class 31, at the corners of a cube, .	4	1 pair	6	3 pairs

6. A group containing twelve similar balls similarly placed will, if the situations of the twelve balls are *identical*, belong to one of the classes 9, 10, 28, 29, 30, 31, or 32. If the similar situations of the balls *form two sets enantiomorphously related*, it will belong to one of the classes 11, 12, 13, or 17. The situations of the ball-centres in groups of classes 9, 28, 29, 30, and 31 are

singular points. Groups of classes 10, 29, or 32 are not identical with their own mirror-images, consequently exist in two enantiomorphous forms.

The number of groups obtainable by *twofold* substitution, given under two heads A and B as before, is as under:—

Description of group of similar similarly situated ball-centres before substitution is made.	NUMBER OF GROUPS DERIVABLE.			
	A		B	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Twelve-Ball Groups.				
12*a*, Class 9, the ball-centres lie at the corners of a regular hexagonal prism,	9	2 pairs	11	4 pairs
12*b*, also Class 9, two and two on the sides of a regular hexagon equidistant from the angles, ...	9	—	11	—
12*c*, Class 10, form a 12-point-group of the hexagonal system which has no planes of symmetry (an enantiomorph), .	9	—	11	—
12*d*, Class 28, at the middle points of the 12 edges of a cube, ...	5	1 pair	6	2 pairs
12*e*, Class 29, at the middle points of the 12 edges of a cube (an enantiomorph),	5	—	6	—
12*f*, Class 30, form a specialized regular 12-point-group whose points lie in planes which pass through opposite edges of a cube, ...	7	2 pairs	11	5 pairs
12*g*, Class 31, form a specialized 12-point-group whose points lie in planes through principal axes, . . .	7	2 pairs	11	4 pairs
12*h*, form such a 12-point-group further specialized so that each point is equidistant from 5 nearest points, which consequently lie at the angles of a regular pentagon; other balls if present being arranged in this higher symmetry,[1]	3	—	3	—
12*i*, Class 32, form a 12-point-group without planes of symmetry (an enantiomorph), ...	7	—	11	—
12*j*, Class 11, at the corners of a regular hexagonal prism, ...	12	5 pairs	22	11 pairs
12*k*, Class 12 (for form see Sohncke's fig.),	14	5 pairs	22	11 pairs
12*l*, Class 13 (for form see Sohncke's fig.),	14	5 pairs	22	11 pairs
12*m*, Class 17, on the sides of a regular hexagon equidistant from the angles,	12	3 pairs	22	11 pairs

[1] Although a group of this kind can form the unit of a homogeneous assemblages, the symmetry of the group is not such as can be possessed by the assemblage.

7. A single type of group containing sixteen similarly-placed balls, in which the similar situations of the balls form two sets enantiomorphously related, belongs to class 21, the situations of the balls not being singular points, and the form being identical with its own mirror-image.

NUMBER OF GROUPS DERIVABLE.			
A.		B.	
Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
20	7 pairs	30	15 pairs

8. A single type of group containing twenty similarly-placed balls can be obtained by occupying the twenty similarly-situated points lying midway between every nearest three points of the specialized 12-point-group referred to under 12 *h.* above,[1] the form obtained being identical with its own mirror-image.

NUMBER OF GROUPS DERIVABLE.			
A.		B.	
Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
6	1 pair	7	2 pairs

9. A group containing twenty-four similar balls similarly placed will, if the situations of the 24 balls are *identical*, belong to one of the classes 28 or 29. If the similar situations of the balls *form two sets enantiomorphously related* it will belong to one of the classes 9, 30, or 31. The situations of the ball-centres in class 28 are singular points. Groups of class 29 are not identical with

---

[1] When a homogeneous assemblage is built up of such groups, although the twenty balls occupy similar positions so far as a single group is concerned, they will not all occupy similar positions in this assemblage.

their own mirror-images, consequently exist in two enantiomorphous forms.

The number of groups obtainable by *two-fold* substitution given under two heads A and B as before, is as under :—

Description of group of similar similarly situated ball-centres before substitution is made.	Number of Groups derivable.			
	A		B	
	Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
Twenty-four-Ball Groups.				
24*a*, Class 28, the 24-ball-centres arranged to form a specialized 24-point-group whose points lie in planes drawn through the cube centre perpendicular to the three principal axes, . .	16	4 pairs	23	8 pairs
24*b*, also Class 28, 24-point-group whose points lie in planes drawn through opposite cube edges, . . .	16	5 pairs	23	10 pairs
24*c*, Class 29, form a 24-point-group without planes of symmetry (an enantiomorph)	16	—	23	—
24*d*, Class 9 (for form see Sohncke's fig.), .	30	11 pairs	46	23 pairs
24*e*, Class 30 (for form see Sohncke's fig.),	26	10 pairs	46	23 pairs
25*e*, Clsss 31 (for form see Sohncke's fig.),	26	11 pairs	46	23 pairs

10. A group containing forty-eight similar balls, the similar situations consisting of two sets *enantiomorphously related*, can be formed of class 28, and the number of groups obtainable by *two-fold* substitution from such a group is :—

Number of Groups derivable.			
A.		B.	
Balls substituted alike.	No. of Enantiomorphs.	Balls substituted different.	No. of Enantiomorphs.
56	23 pairs	94	47 pairs

In precise harmony with the conclusion stated above, that in

a group of similar identically-situated balls substitution *for one only* will produce identically the same effect whichever of the similar balls is selected for removal,[1] we have the fact of the presence in some combinations of similarly situated atoms, *i.e.*, of atoms whose ties are similar; the proof of this being that there is but one mono-substitution product of such combinations, *e.g.*, of methane, and that this is the case notwithstanding the employment of methods which ensure that different atoms and not the same atom are displaced in a series of displacements of a single atom.[2]

That the atoms have distinct spheres of influence, and, although similarly related to the combination in which they occur, are not without relative arrangement of some kind is in evidence. Thus we have two and not merely one tetra-substitution derivative *a b c d* of Methane.[3]

Corresponding to the limited number of ways in which double substitution can be made in the simpler groups, as shown by the tables given above,[4] we have the facts referred to by Lothar Meyer as follows:—

" The circumstance which has especially conduced to the wide recognition of Kekulé's hypothesis is the fact that hitherto but three mutually isomeric di-substitution products of the benzenes have been obtained, *e.g.*, but three dichlorobenzenes, and that this continues to be the case in spite of the great efforts made by many investigators to find a fourth.[5]

The formation employed by Kekulé for the cases just referred to is the hexagonal one marked 6*a* in the list just given. One of the other simple arrangements 6*d* or 6*e* would, however, give the

---

[1] See p. 609.

[2] Comp. Lothar Meyer's " Grundzüge der theoretischen Chemie." Note, p. 96. In speaking of the " Schablone " of Kekulé, Lothar Meyer says: " By the ring form here referred to it is not intended to be conveyed that the atoms probably lie in a plane ring, but merely that they form a chain whose ends are connected, *i.e.*, a ' closed ' chain."

[3] Comp. the law of le Bel and van 't Hoff. " Atoms or groups connected by four valencies are unable, wanting some other condition, to exchange places with one another." *Proof*—There are but two tetra-substitution products of methane *a b c d*. See Satz IV. Bischoff's " Handbuch der Stereochemie," p. 50.

[4] See in particular pp. 611–613 above.

[5] Lothar Meyer's " Grundzüge der theoretischen Chemie," p. 87.

same number of different derivatives *if two enantiomorphs count as one form only*, which they may do if they occur together in the same assemblage of groups and are not separable. The simple octahedral arrangement marked 6 *j* is too symmetrical for the requirements of the case, as in it but two kinds of double substitution are possible.

Usually substitution of a different ball for one of several of the same sort will cause equilibrium to be found in a homogeneous assemblage of a different kind, commonly of a different type; there may, however, be cases in which the influence of the balls *common to both assemblages* is so predominant that the kind of internal symmetry is the same in both. This would almost certainly be the case if the balls changed were inoperative ones.[1] We should expect that in most cases more or less similarity of arrangement of the unremoved balls would exist and would produce some resemblance between the assemblages thus related.[2]

The similarity of crystallographic form displayed by some compounds and their derivatives, *e.g.*, some benzene derivatives, may be compared with this.[3]

With regard to those homogeneous assemblages which consist both of groups and of loose balls, or of two or more kinds of groups, it is evident that for such to be stable, the different kinds of groups must, as to their configuration and their repulsions, be sufficiently adapted to one another to produce very close-packing; otherwise the assemblages would not be likely to be examples of stable equilibrium. We shall, therefore, in the case of assemblages of this nature have a close fitting together of different groups which does not lead to a linking together of those groups capable of surviving in the liquid condition[4] with which we have been dealing.

And for comparison with this, we may cite the loose chemical ties found in crystal bodies which break up as they dissolve, *i.e.*, in those in which so-called water of crystallization enters into the composition of the crystal, and in most double salts.[5]

---

[1] See p. 547. [2] Comp. p. 647. [3] Comp. 662 below. [4] See p. 583.
[5] Compare Fock's "Chemical Crystallography," Pope's translation, pp. 29 and 36.

III. **Symmetrical intercalation of homogeneous assemblages whose
forms are identical or appropriately related, comprising for-
mation of twin assemblages, including under this head the
symmetrical fitting together of enantiomorphously related
assemblages as well as that of identical assemblages, forma-
tion of isomorphous assemblages and their intermixture, and
the symmetrical interlocking of unlike assemblages. Com-
parison to crystal-twinning, isomorphism, isogonism and
crystalloid[1] structure, also to some kinds of diffusion.**

Hitherto the cases of intermixture of balls of different sizes
resulting from the principle of closest-packing, with which we have
dealt, have, with one or two exceptions,[2] been cases of *homogeneous*
intermixture, *i.e.*, the resulting assemblages have been made up of
entirely similar space-units ; we have now to deal with certain more
or less symmetrical combinations which result from the action of
the same principle, but which are not homogeneous, although com-
posed of portions of assemblages which are so.

Checked development of symmetry—Accidental twinning.

When in an assemblage which is of practically uniform compo-
sition soldification[3] commences at two or more points independently,
and coalescence of the growing nuclei at which solidification is taking
place occurs before the closest-packed arrangement is fully reached,
imperfections in the symmetry will present themselves. These
may be considerable, so that the mass consists of a number of small
similar homogeneous assemblages which meet quite unconformably,
or they may be inconsiderable, so that the various fragmentary
homogeneous assemblages which make up the mass are nearly, but
not quite sameways orientated, the portion of the mass lying
between the nuclei which is last to solidify having to accommodate
its arrangement to some slight irregularities produced through the
solidification having at some points advanced rather faster than has

---

[1] Unfortunately the word crystalloid is used in two distinct senses. In these pages
it always denotes those regular crystalline bodies which are capable of imbibition.
[2] See p. 568 and p. 548.   [3] See note 1, p. 530.

the arranging for closest-packing. *Or, if the change of state be sudden, some differently-orientated portions which are unable in the time to get similarly-orientated, may find themselves able to fall into some relative orientation which, though it does not give such close-packing as the same-ways orientation would do, comes but little short of it.*

Very symmetrical fitting together of differently-orientated identical assemblages, such as might furnish cases of the kind last referred to, can often be obtained if a single homogeneous assemblage be divided by a principal plane, *i.e.*, a plane which intersects a great number of contiguous similar ball centres, or one which lies evenly between two successive similar planes which do so ; and the half of the assemblage on one side of the plane be turned through 180° about an axis occupying a certain position perpendicular to the latter. Or in cases where the symmetry of the plane of centres taken alone is such that it has a digonal axis *which lies within it*, the rotation may be made about this axis, but in this case duplicates of the same half of the assemblage differently orientated will be fitted together, and not the two halves of the same individual assemblage differently orientated.

The differently orientated fragments of an assemblage which are thus combined may be of the same or of different size.

It will be characteristic of twinning caused in this way that the phenomenon will be promoted by any condition which hinders the mutual adjustment requisite for the production of homogeneity, its occurrence will be fortuitous, and it will be done away with as the conditions are made more favourable to the unchecked operation of the principle of closest-packing.

Crystals furnish types of aggregation corresponding to all the cases mentioned ; indeed most crystals that appear to be single individuals are built up of more or less numerous distinct crystals which are not quite parallel in orientation to one another, though continuous in their substance and in optical contact. The symmetrical union of differently orientated individual crystals of the same kind which is known as *twinning* furnishes parallels to the case last named.

Only those cases of crystal twinning can, however, be claimed as resemblances to the accidental twinning of identical homogeneous assemblages above referred to, *in which no repetitions or*

frequency or constancy of occurrence are presented which are incompatible with fortuitousness. Where, for example, all or most of the crystals of a substance which are found at a given spot are twinned it is evident that some definite predisposing cause, and not mere accidental inability to attain a more stable equilibrium, must lie at the root of the phenomenon.

That there are many instances in which the twinning of crystals is an accidental occurrence may be inferred from the observations of Lehmann, which show that the greater the viscosity of a solution the greater is the branching (Verzweigung) of the crystallization, some of which leads to twin production.[1]

If the form of an assemblage which gives closest-packing has enantiomorphous symmetry, and consequently admits of two kinds, right-handed and left-handed, both of which are packed equally close, it is evident that accidental twinning of these two kinds together may be produced in the way suggested, by rapid change of state ; *and not only so, but that this kind of twinning is likely to occur wherever solidification of the mass originates at more than one nucleus.* For this will stereotype arrangements of both kinds, if such happen to be present at the different centres, and will consequently prevent either arrangement from extending its boundaries to absorb the entire assemblage, however much the principle of closest-packing may favour such a proceeding.

It may be remarked at this juncture that, except in one class of cases, *the nature of the surface separating the individuals forming a twin assemblage is manifestly completely determined by two factors,* (1) the relative situation of the nuclei, or centres, from which the individuals respectively commence to grow ; (2) the relative rates of growth, at every moment, of juxtaposed faces, one of each individual, which meet in the separating surface. Any symmetrical arrangement of the juxtaposed faces, and consequently any symmetry of form of the separating surface will depend on the relative orientation of the individuals.

The cases which furnish the exceptions, in which an additional factor comes in, are those in which two faces thus meeting are in the same plane. For it is evident that the separating surface can

---

[1] Zeitschr. für Kryst. I., p. 484.

then, consistently with the above two factors, quite arbitrarily take any continuous form.

If any irregularity or modification of the rate of growth is caused at any surface of one individual by the proximity of a surface or surfaces of another individual, or by any other means, it is evident that the conformation of the separating surface will be thereby affected.

Further, although the principle of closest-packing may be expected to fit the two nuclei of a twin assemblage together in a very symmetrical manner at the outset, it does not follow that *after coalescence has once commenced*, there will be any specially symmetrical fitting together of the growing individuals at the separating surface ; for the relative situations and rates of growth being, as has just been said, the *only* factors determining the *locus* of the separating surface, no latitude is left for the principle of closest-packing to produce symmetrical fitting together of the growing individuals.

As a direct consequence of this it may be concluded that the locality of the separating surface must commonly be a place where symmetry is disturbed and which is not therefore very favourable to symmetrical growth, and to compare with this there is the fact that although single crystals never exhibit re-entrant angles, the occurrence of these angles between distinct crystals which are juxtaposed, whether as twins or otherwise, is extremely common.

Twinning caused by dimorphous change.

If the conditions of equilibrium of an assemblage undergo a dimorphous change which causes it to cease to find equilibrium in one kind of homogeneous arrangement and to approximate towards some other as the closest-packed arrangement,[1] the rearrangement of the parts which takes place will, unless a very radical one indeed, be facilitated by some uniform distortion of the assemblage as a whole. And this distortion may consist of one or more linear shrinkages or expansions of the assemblage as a whole, or of some simple shear which slides its layers on one another, or of some combination of these simple methods of modifying form without

---

[1] Comp. p. 575.

materially affecting relative distribution of parts. This will especially be the case when the change is from one system of symmetry to another. If, for example, an assemblage passes from cubic to rhombohedral symmetry, much, if not all, of the consequent rearrangement will, in general, be most readily effected by a uniform distortion of the mass which alters the angles of the cubical space-lattice so as to convert it into a rhombohedral one. And if redistribution of the parts is hindered by the partial solidification of the mass, the predominance of this general distortion in the arranging process will be the more pronounced.

Now if in the case of an assemblage which is thus changing its form as a consequence of change in the conditions of equilibrium, the external and other conditions render it easier for the assemblage to effect the alteration of form *in sections whose directions of expansion and contraction are not the same, rather than as one undivided individual,* sections or blocks differing in orientation will be produced, and, as the principle of closest-packing will require as great an economy of space as possible to be practised, these sections or blocks will be very symmetrically related to one another: in other words, a twinned assemblage will be produced. And the condition which makes it easier for the change to take this shape may be restraint of alteration of form arising from the situation of the assemblage within or in contact with solidified masses of some sort, either of the same or of some different composition.

To make this clearer, let us take the following simple example:

Suppose that, under certain external conditions, a number of similar complexes of balls are found when closest-packed to be arranged with their centre-points at the centres of the prisms of a system of identical hexagonal prisms with plane ends symmetrically fitted together to fill space, all the group centres lying therefore directly over one another in the arrangement shown in fig. 17.

If now the conditions change so that the complexes when arranged as just described are no longer in equilibrium, but attain equilibrium in a simple cubic arrangement,[1] the alteration in the

---

[1] This necessitates the form of a single complex being compatible with cubic symmetry.

arrangement involved by the necessity for closest-packing may be accomplished by a simple *shear* which slides layers of the complexes that are vertical to the plane of the diagram on one another in a uniform manner, taken in conjunction with a simple linear expansion or contraction of the assemblage as a whole.

For if the direction of the projection of the shear be indicated by the line *AB*, and each of the layers of particles referred to be moved vertically to the plane of the diagram upon the layer next to it a distance $\frac{\lambda}{3}$, where λ is the vertical distance between succeeding horizontal layers in the original disposition, we obtain a
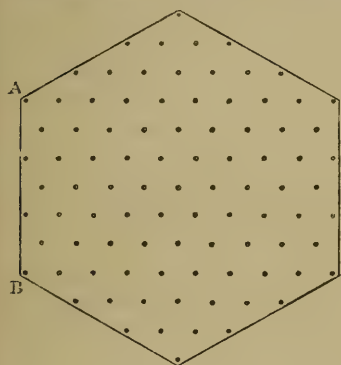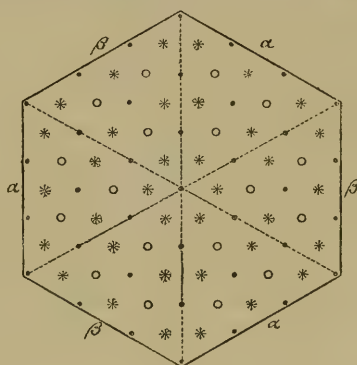
Fig. 17.   Fig. 18.

rhombohedral arrangement. And this rhombohedral arrangement can by appropriate shrinkage or expansion in the direction of the principal axis be so distorted that the points shall come to lie either—

1. At the centres of half the cubes of a system of cubes filling space symmetrically chosen.

2. At the centres of all the cubes.

3. At the centres *and* solid angles of all such cubes.

Now, if the change of external form involved by the shear is opposed by some restraining influence, it may be easier, in place of a single shear, for six simultaneous similar shears to take place in such a way that the plane layer of points represented by fig. 17, becomes the six slant faces of a six-sided pyramid. The symmetry of the arrangement thus reached is indicated by fig. 18, in which

the projections of points lying at different distances from the plane of the diagram are differently indicated.

The result of this compound shearing, accompanied by an appropriate linear shrinkage or expansion of the mass, is therefore to produce an interpenetrant twinning in the cubic symmetry, the portions marked a being similarly orientated and indeed continuous in arrangement, but having the opposite orientation to those marked β, which are also similarly orientated and continuous in structure among themselves.

The kind of twinning thus reached is frequently exhibited by fluor-spar, and by galena.

In all cases, at least two shears in different directions, opposite or otherwise as the case may be, will be needed to accomplish twinning by dimorphous change in the way just explained. If there are but two shears there will be only one separating surface, and the twin assemblages formed will not be interpenetrant.

The arrangement of parts prevailing in two adjoining blocks which shear in different directions may, after the shearing has taken place, bear an identically-similar relation to the surface separating the blocks, or they may bear an enantiomorphously-similar relation, in which they will generally be symmetrical or mirror-twins. In the latter case the two arrangements will be enantiomorphous *unless they are identical with their own mirror-images.*

Mirror-twin tetragonal crystals of copper pyrites furnish an example of twinning in which the two individuals bear only an enantiomorphously similar relation to the separating plane, although they themselves are identical and not mere enantiomorphs.[1]

Multiple twinning.

Interpenetrant twinning originated in the way just indicated, may be described as a method of multiple twinning in which the identity of orientatation of the parts of alternate individuals of the twin system causes these alternate individuals to function collectively as a single individual, thus making it possible to regard the

---

[1] See L. Fletcher "On twins of copper pyrites." London, Edin., and Dublin Philosophical Mag., Series 5, vol. xiv., p. 276.

entire system as composed of but two individuals which inter-penetrate one another.

If instead of the surfaces of movement meeting in an axis, as in the case above given, they are parallel to one another, it is evident that the same cause will lead to the production of parallel twinning, *i.e.*, the kind of twinning called "polysynthetic." A good deal of the latter twinning may be expected to be of the symmetrical ("mirror-image") form, and when the closest-packed arrangement is an enantiomorph, this will of course result in the alternation of right-handed and left-handed forms for the parallel layers.

If the dimorphous change of an assemblage does not take place everywhere throughout it *at the same instant*, this alone may suffice to produce twinning, without the intervention of any *external* restraining influence on change of form. For if, at a certain instant, part only is prepared to distort, the inflexibility of the remainder may make it easier for the distorting portion to change its form in twinned blocks in the way described rather than as a single individual. The nature of *the external form* of an assemblage subjected to a dimorphous change gradually asserting itself from without would evidently be an important factor in determining where the separating surfaces of the different blocks should come.

If a dimorphous change involves *no appreciable alteration in the situations of the principal singular points*[1] of a homogeneous as-semblage, but only some slight changes in the distances between the ball-centres, while leaving the general distribution of them much the same, then the assemblage can undergo change *while continuing solid*,[2] passing from one system of symmetry to the other without any material change of volume or of shape; and, since the transition is not accompanied by any appreciable general distortion, it may extend itself gradually, and not affect the whole mass at once.

---

[1] Singular points in a homogeneous structure are points which occupy specially symmetrical situations, and so form point-systems containing fewer points than ordinarily; they lie on axes of rotation or on planes of symmetry, or on both. Comp. Zeitschr. f. Kryst., 23, p. 60.

[2] See note 1, p. 530.

Further, if the alteration is from a higher to a lower symmetry, and commences at the outer boundaries of the mass, *i.e.*, at the place where any trifling local movements are, in one direction, quite unfettered, the shape of the mass may have some influence in determining from how many centres the change shall simultaneously originate; and thus, if the form of the mass be symmetrical, the number of differently-orientated sections in which the lower symmetry presents itself may bear a definite relation to the number of different orientations of similar parts found in the higher symmetry. At the same time any very slight discrepancies in the conditions at different corresponding points of the mass will suffice to prevent the growth about different origins from proceeding at the same rate, and will cause the boundaries ultimately determined by the relative progress of the metamorphosis spreading from different neighbouring origins, to present much irregularity.

It will be seen that a change of a solid assemblage of the kind just described, if it involve no dislocation, *will be reversible, i.e.*, if after undergoing the change the conditions alter appropriately, the mass will revert to the original symmetry, and be capable of oscillating to and fro from one type of symmetry to the other. Very slight variations in the successive changes will, however, suffice to alter the precise situation of the boundaries of the sections from time to time as the lower type of symmetry recurs.

Moreover, for reversibility to be possible there must be no accretion to the assemblage after passing from the higher symmetry, that is unless the change be accomplished with absolute freedom from strain. For unless this ideal condition is realized, the growing portions of adjoining individuals will come together unsymmetrically, *i.e.*, the space-lattices formed by their singular points will not make one continuous system; and in this respect the newly-formed compound assemblage will differ from the old, and be incapable of passing as a whole to the higher symmetry.

If there be accretion after the change, and consequent deterioration of the symmetrical relation at the newly-formed boundaries, we must not look for reversibility, but in other respects there may be no prominent properties to enable us to distinguish this from a case in which reversibility is possible.

In connection with these conclusions two facts with regard to

substances whose crystals undergo dimorphous change may be noted.[1]

(*a*) When the change takes place the position of the new modification bears some symmetrical relation to that of the old.

(*b*) When but a slight change of volume is associated with the change, strains are set up which are partly relieved by fractures, and by the sliding of laminæ on one another, complete destruction of form being thereby avoided.

For comparison with the suggestion that the portion of an assemblage growing after a dimorphous change has taken place may be somewhat differently fitted together, we may cite the not uncommon phenomenon of the existence of optically normal nuclei (Kernen) in anomalous crystals.[2]

For comparison with the reversible cases, there are certain substances, *individual crystals* of which present two different dimorphous states as the conditions are changed. One of the most signal instances of this is that described by Mallard as occurring in the case of boracite.[3]

A crystal of this substance at temperatures above 265° is found to belong both in form and structure to the cubic system, being of tetrahedral-cubic symmetry; but the same individual crystal, when the temperature falls below this point, although it preserves its external form, displays properties which show that its structure has passed to a lower symmetry. It does not make the change as a single individual, but ordinarily in six or twelve portions whose corresponding axes are symmetrically placed with respect to the faces of the crystal, adjoining individuals being, however, very much interlocked, and showing indeed no more regularity than suffices to mark out the definite number of differently orientated portions, or most of them, without giving to them any uniformity

---

[1] Brauns, " Optischen Anomalien der Krystalle." Leipzig, 1891, §§ 3 and 4, p. 87.

[2] Ben Saude, " Die wahrscheinlichen Ursachen der anomalen Doppelbrechung der Krystalle." Lissabon, 1896, p. 26.

[3] Mallard, " De l'action de la chaleur sur les substances cristallines." Bull. min. V., pp. 216-219. Comp. Bull. min. VI., p. 122.

Another instance is furnished by potassium chlorate. A homogeneous crystal of this substance when heated to about 245° twins polysynthetically. (See Madan in "Nature," vol. xxxiv., p. 66, and Rayleigh, Philosophical Magazine, 1888, II., p. 260.)

of outline.[1]   The general features of the allotment of the substance of the crystal to the different individuals are to some extent dependent on the relative predominance of particular external forms.   The crystals when in the less symmetrical of the two dimorphous states exhibit strong double refraction.   The change of structural symmetry is indicated both by the optical properties, and also by the nature of the figures etched on the crystal faces.[2]   The boundaries between the individuals, which vanish when the change to the regular form takes place, do not reappear in the old places when the crystal cools again, but commonly occupy quite different situations.[3]   The change of volume produced by the passage from one type of symmetry to the other is very inconsiderable, but there appears to be some slight strain induced by it which causes the crystals to become brittle, and pyroelectric properties are acquired. The optic axes of the less-symmetrical form are inclined at 90° to one another, and are always normal to the direction proper for some cube face, whether that face be actually present or not.   The bisecting line between the axes[4] is always vertical to some direction possible for a dodecahedron face, whether the face be present or not.[5]

Again, potassium ferrocyanide[6] possibly furnishes an example of the kind of dimorphous change just explained *in which the alteration takes place in the initial stage of crystallization, while accretion subsequent to it prevents reversibility,* and another example of this kind may be presented by the hydrated crystals of *trans-π-*camphotricarboxylic acid recently obtained by Kipping,[7] and whose optical properties have been ascertained by Pope.[8]

For suppose that a homogeneous assemblage of either tetragonal or hexagonal symmetry *which does not possess planes of symmetry through the principal axis,* undergoes a dimorphous change to a

---

[1] Brauns, *loc. cit.*, p. 91. Sometimes one or two of the individuals are of insignificant size, or even quite wanting.

[2] Baumhauer, "Bemerkungen über den Boracit."   Zeitschr. f. Kryst., X., p. 451.

[3] Klein, "Göttingen Nachrichten," 1881, Nr. 3.   Mallard, "De l'action de la chaleur sur les cristaux de boracite."   Bull. min., V., p. 144.

[4] Since the axes are inclined at 90° this applies to either of the two bisecting lines which appear to be distinguishable optically as *positive* and *negative.*

[5] Brauns, *loc. cit.*, p. 104.   [6] Brauns, *loc. cit.*, p. 58.

[7] Trans. Chem. Soc., 1896, p. 951.   [8] *Ibid.*, p. 978.

rhombic type, the principal axis being retained as the axis of the lower symmetry ; and that the change commences simultaneously and symmetrically in four or in six similar segments of the nucleus as the case may be, and does not effect any material change in the situations of the singular points of the assemblage, or in the general distribution of the parts.

It is then evident that if, when the rhombic form is reached, the optic axial planes are parallel to the axis, symmetry will require them to be inclined to one another symmetrically at equal angles, in the one case of 90°, in the other of 60°.

Further, we see that there being no planes of symmetry between the segments, and their growing surfaces perpendicular to the axis being coincident, *i.e.*, not inclined to one another, the position of the boundary between them will not be fixed by considerations of symmetry, but merely by the relative rate of growth of the adjoining individuals which happens to prevail from point to point. Consequently adjoining twin individuals must be expected to tooth into one another in a very fortuitous manner, the boundary between them in one layer of the growing common surface scarcely ever happening to be directly over the boundary in the underlying layer.[1]

The relative orientation of parts and *gradual* passage from the optical effects proper to one segment to the optical effects proper to the differently-orientated adjoining segment, as the boundary between them is passed, which would be produced in the way suggested appear to be just such as those observed by Grailich and subsequently by Wyrouboff in the case of potassium ferrocyanide, and by Pope in the case of *trans*-π-camphotricarboxylic acid.

There is another way in which a dimorphous change may cause the passage from a higher to a lower type of symmetry and produce scarcely any perceptible alteration of external form, the dimorphous change being under some conditions reversible, under others non-reversible.

---

[1] Comp. p. 623, also Zeitschr. f. Kryst., 27, p. 474.

Examples of intricate interlacing, probably due to dimorphous change in the way described, but where the symmetry is of a lower order, may be called to mind. Thus in the case of aragonite the individual crystals sometimes interpenetrate in such a way that parts of one individual are inclosed in another. Comp. p. 648.

Thus suppose that in a case of multiple twinning,[1] the solid angles at which the twinning blocks fit together are unaffected by the dimorphous change, so that the alteration takes place without rupture or strain ; then it is evident that the change will be perfectly reversible and that a fluctuation of the conditions to and fro past a certain critical point may produce any number of oscillations from one dimorphous symmetry to the other without causing confusion. And we shall see immediately that there need be but very trifling alteration in the external form when the change takes place.

Further, in the ideal case thus put, the reversibility will still hold good if the mass is a growing one, the junctions formed between growing individuals after the dimorphous change has taken place being as symmetrically constituted as those produced at the time of this change.

But if the solid angles between the blocks are not absolutely unaffected by the dimorphous change, some strain or rupture being involved in the continuance of the twinning blocks in their original relative situations, we see that, although so long as there is no accretion after the change has taken place reversibility will still be possible if the strain or shifting is but very slight, *if growth takes place*, the added portions, however slight the strain, will come together more or less unconformably at their boundaries. And that the less symmetrical character of the newly-formed junctions as compared with those produced at the time of the dimorphous change which owe their constitution to the higher symmetry of the original form, will be a hindrance to any reversal of the dimorphous change after it has once taken place.

With reference to the change of external form, slight or otherwise, involved by a dimorphous change which leaves the solid-angles at which the twinning-blocks fit together entirely or almost entirely unaffected, we note that in cases where all the twinning-blocks meet in a single point—as they will, for instance, where the change is from a cubic symmetry—if the change involves but slight distortion, a single face or plane-direction in one symmetry may be transformed in the other into a set of pyramid faces inclined at

---

[1] See above, p. 626.

very large angles to one another, and when the alteration is very trifling indeed, the existence of these slightly-inclined planes (vicinal planes[1] of the mineralogist) and some slight discrepancies in the angular values may be the only morphological evidence presented of the dimorphous change having taken place.

A reference to particular cases, accompanied by comparisons with corresponding phenomena displayed by crystals, will, it is hoped, make these matters clearer.

For example :—An assemblage which has tetrahedral cubic symmetry can, by an appropriate dimorphous change, be transformed to monoclinic symmetry, with but slight alteration of arrangement and in a manner compatible with the preservation of the general features of the tetrahedral form, in the following manner.

Somewhere in the assemblage draw a regular tetrahedron with its principal axes coincident with trigonal axes of the assemblage.[2]

Join the angular points of the tetrahedron with its centre, thus outlining a partitioning of it into four blocks each of which is a right triangular pyramid, the vertices of the four pyramids coming together at the centre of the tetrahedron.

If now each of these four triangular pyramids experiences a similar uniform linear distortion, say an expansion, in the direction of its perpendicular, it is evident that the four vertices can no longer fit up together.

But if each of the four pyramids be divided into three equal segments by planes perpendicular to its base drawn through the slant edges, and each of the twelve similar segments thus obtained be subjected to an appropriate simple shear which slides on one another planes of centres which are vertical to the pyramid base and parallel to the side of this base which bounds the segment, *the alteration of the solid angles at the tetrahedron centre caused by the linear distortion can be exactly compensated by these shears and reduced to zero.*

Therefore twelve segments or blocks of a tetrahedral assemblage

---

[1] It is not suggested that this may be the origin of all vicinal planes, but only of those occurring in cases of the kind here referred to.

[2] For this to be possible, the assemblage must be of one of the types in which the trigonal axes intersect one another. A slightly modified method must be pursued in the cases of the less regular types.

which fit up together as described can undergo linear distortions and compensating shearing in the way above explained without separating one from another at their planes of contact.

Consequently if the given assemblage is subjected to a change of conditions of such a nature that on reaching a critical point the cubic symmetry ceases to give closest-packing, and some arrangement which would be obtained by means of compound distortions whose components are related as just prescribed, becomes the closest-packed arrangement, and if, further, the change can occur more easily if there is a minimum of alteration of the external shape, then *a passage from one dimorphous form to the other will take place in segments in the way indicated without rupture or strain.*

There will however, be some alteration of the dimensions in directions radiating from the centre, and in the case supposed, in which linear *expansions* are combined with appropriate shearing, the plane surfaces of the original tetrahedron will be raised up at their middles so as to be converted into triangular pyramids. And if the change of form be but slight, the faces of these pyramids will be very slightly inclined to the tetrahedron face from which they originated, and will therefore be what are called in crystals *vicinal faces.*

The result of the combined distortions will be to convert the cubic symmetry into monoclinic symmetry.

If in the case just supposed planes are drawn through the tetrahedron edges so as to form a cube, the cube-faces after the distortion will be found each to consist of two planes inclined at a re-entrant angle of nearly 180°, the angle edge running along one of the face diagonals.

As to other ways, besides the one just given, in which an assemblage in cubic symmetry of the tetrahedral or of some other class, can be transformed to a lower symmetry without strain or rupture and with but slight alteration of its parts:—Instead of the regular tetrahedron we can employ some other regular polyhedron possessed of the requisite cubic symmetry, and the faces of which are regular polygons whose sides are all similarly related to the structure of the assemblage.

Thus we can make use of a cube or of a rhombic-dodecahedron placed in a symmetrical manner in the assemblage.

As before, we shall join the angular points with the centre of the figure and have linear distortions perpendicular to the polyhedron faces compensated by appropriate shearing of the segments which are obtained by drawing planes perpendicular to these faces through their angles.

In all such cases it is not difficult to see that the polyhedron faces will be elevated or depressed at their middles by the combined effects of the distortions so as to be converted into pyramids whose vertices point outwards or inwards as the case may be, and if the distortion be trifling the faces of the pyramids will be but slightly inclined to the direction of the face from which they were derived.

We have said that if the shearing exactly compensates the linear distortion so far as the effect on the solid angles of the blocks or segments which fit together at the centre of the polyhedron is concerned, there will be no rupture or strain at the surfaces of contact between these twinning blocks. If, however, the compensation is not very exact we may expect evidence of more or less disorganisation of the parts of the assemblage, such as small rifts, or strains, or traces of shear; although at the same time the general change of form may take place in a fairly symmetrical manner. This, as we shall see immediately, is important.

If any operations, analogous to those just traced, take place in nature we must expect that in all cases where the alteration in arrangement brought about by the dimorphous change is very slight, the boundaries of the twinning-blocks will only roughly approximate to the situations in which they would be found in an ideal case where the conditions are supposed perfectly uniform at all morphologically-similar points.

In the ideal cases, where no strain and very little deformation are caused by the passage from the higher to the lower symmetry, it may well be that so little change in the arrangement and interaction of the parts takes place that there is little or no perceptible departure in the lower symmetry from the optical properties of the original higher symmetry, *e.g.*, in the case of a cubic crystal changing to a group of monoclinic individuals, no appreciable departure from isotropism in the latter. Where this is so there may be nothing but the presence of the vicinal faces to

betray the fact of a dimorphous change having effected the alteration to a lower symmetry.

For comparison with the foregoing geometrical conclusions we have various instances of the presence of vicinal-faces on crystals, in very many of which the fact of the existence of pseudo-symmetry is revealed by the optical properties not being in harmony with the higher symmetry.[1]

Among these may be mentioned the pseudo-tetrahedrally-cubic *pharmacosiderite* whose cube faces consist of two planes inclined at a re-entrant angle of nearly 180°, the angle edge running along a diagonal. Six individuals are discernible in each crystal which interlock in the neighbourhood of planes drawn through opposite cube edges. They are double-refracting, and sometimes the separation of one of these individuals into two halves by a diagonally placed boundary is indicated optically by the different extinction-position for one half as compared with the other. There are some remarkable optical peculiarities.[2]

Brauns notes that among the alums, mixed crystals with vicinal faces are biaxial,[3] a fact which suggests that that which produces these vicinal faces also produces a lowering of symmetry.

It is, as has been said, conceivable that a dimorphous change which lowers symmetry may reveal itself by the production of vicinal-faces in the way above indicated, but that the change in the arrangement of the ultimate parts which it produces may be so slight as to have no perceptible effect on the optical properties. And the pure alums which crystallize in the cubic symmetry with vicinal-faces but are isotropic,[4] may exemplify this.

We have already called attention to the fact that if the solid angles at which the twinning-blocks meet are not absolutely unaffected by the dimorphous change, some strain or irregular shifting of parts will be involved in the continuance of the blocks in their original relative situations. The nature

---

[1] Comp. A. Ben Saude, " Die wahrscheinlichen Ursachen der anomalen Doppelbrechung der Krystalle." Lissabon, 1896. Note 2, p. 14.

[2] Brauns, *loc. cit.*, p. 349.

[3] Brauns, *loc. cit.*, p. 237.

[4] Brauns says that only those alums which contain isomorphous admixtures exhibit optical anomalies. *Ibid.*, p. 228.

of the shifting, if it occurs, will evidently much depend on what surfaces of weakness are present in the structure, *i. e.*, what cleavage planes, gliding planes dependent on cleavage planes, &c.[1]

Suppose, for example, that a cubic structure undergoes a dimorphous change which divides it into six individuals of square-pyramidal form, each of which experiences an expansion along its perpendicular. Then, if the individuals are to remain in contact as before, and the dimorphous change does not produce the precise shearing requisite to neutralize the change of the solid angles of the individuals that fit up together which is produced by the expansion,[2] there will have to be some shifting of parts along lines of weakness.

If now planes parallel to the cube faces are not planes of weakness, but planes parallel to dodecahedron faces are, and no others, we must look for such a shifting along the latter directions as will, on the whole, be practically equivalent geometrically to the balance of the shearing, which has by some means to be made up in order to exactly compensate the effect of the expansion at the solid angles.

Now the resultant of two equal similar shears perpendicular to a cube face, having the directions respectively of two dodecahedral faces inclined to one another at 90°, is a single shear also perpendicular to the cube face and having the direction of a second cube face. The shifting in the case supposed will therefore largely consist of a number of movements along every two dodecahedral plane directions thus related, the amount of movement in each being somewhere about the same.

As already remarked, if the shifting in a case of this kind is inconsiderable, it is conceivable that it may not prevent reversibility of the dimorphous change, *so long as no accretion has taken place since the change.*

If the general movement is small, and shifting can easily take place, but little strain may be set up, and the relations between the parts may be but little altered by the change, and thus but little removed from those appropriate to the higher symmetry.

---

[1] As to how gliding planes may be connected with cleavage planes, see p. 645.

[2] Comp. p. 633.

Over against these conclusions we may set the facts regarding leucite.[1]

The pseudo-holohedral-cubic crystals of this substance are marked with numerous striæ, which are due to the presence of twin lamellæ, whose direction is that of the rhombic-dodecahedral faces, whether such are actually present on the crystal or not; there is also optical evidence of the presence of thin lamellæ which have apparently served as gliding planes in the transition to the lower symmetry.[2]

The following is evidence that the crystals have undergone such a transition.

At a red-heat they become isotropic, all the surface markings which are attributable to the presence of twin lamellæ vanish, and every face becomes as to form and position uniform throughout and free from deformation; internal irregularities also disappear.

When reversal takes place local peculiarities are to some extent, but not entirely, found reappearing at the same spots. In the case of thin plates especially the alterations which present themselves on the reversion to the former symmetry are considerable.

Three principal interpenetrant individual portions are in many cases traceable by their optical properties, but they are commonly of various magnitudes; they approximate in the more perfect examples to square right pyramids meeting at their vertices, and of which the opposite ones, two and two, have their general structure similarly orientated, and so appear to form a single individual.

At ordinary temperatures the angles differ somewhat from the values proper to the cubic symmetry.

Like leucite, one of the uranyl double acetates shows twinning lamellæ when in the less symmetrical of its two dimorphous forms, and loses them as the temperature is raised. And the behaviour of re-entrant angles but slightly removed from 180°, which are found on the rhombohedron faces is, as a certain critical point is reached, particularly instructive, the indented edges moving outward and forming straight lines as isotropy sets in, and the indents in the rhombohedron faces at the same time vanishing. The process is reversible.

---

[1] Brauns, *loc. cit.*, p. 106.
[2] This is Rosenbusch's suggestion. Comp. *Ibid.*, pp. 51 and 109.

Etched figures on the crystal faces appear to have a form quite independent of the twinning which takes place, showing that the latter does not effect sufficient change of structure to modify this phenomenon.[1]

Probably the optical anomalies presented by fluorspar have a somewhat analogous origin. This suggestion receives support from the fact that sections taken from the middle of a crystal showed the same optical behaviour as those taken near the surface, and it is in harmony with the fact that the optical peculiarities remain practically unchanged by rise in temperature,[2] which they would not be likely to do if the optical anomalies were traceable to strain. Brauns notes that the modifications in the etched figures observed in a specimen of fluorspar from Cornwall are of such a nature as to be explicable by the assumption that linear disturbances of the molecular structure having a direction parallel to the axis of the accretion segment (Anwachskegel) are present which enable the solvent employed to penetrate more readily in this than in the other direction.[3]

Brauns regards microcline as of secondary origin, and it is interesting to observe that a slight shearing of comparatively thin layers, due to a dimorphous change acting on an intractible mass, *i. e.*, on a mass in which general change of shape is prevented, would be competent, as in the case of leucite above referred to, to produce lamination.[4]

And in connection with this it is interesting to note that Förstner has succeeded in making a potash felspar containing sodium pass to the monosymmetric form by heating it.[5]

Microclines, being mixed crystals, some light may be thrown upon the effect of their composition on their stability and readiness to undergo a dimorphous change, when we come later on to consider the probable structure of mixed crystals generally.[6]

---

[1] Brauns, *loc. cit.*, p. 116 ; and see Erb in Neues Jahrbuch VI., Beilage Band, pp. 121–150, 1889.

[2] Brauns, *loc. cit.*, p. 334, &c.   [3] *Ibid.*, p. 337.

[4] Comp. *Ibid.*, p. 133, &c. Brauns' theory is that microcline was originally monoclinic, but, owing to the presence of soda is endowed with instability of form, and thus that long-continued pressure due to gradual mountain movements has been enabled to alter it to the triclinic symmetry. *Ibid.*, p. 146.

[5] *Ibid.*, p. 139.   [6] See p. 647. Comp. Brauns, *loc. cit.*, p. 139.

Anomalous crystals, *i. e.*, crystals whose optical properties betray the existence of a different symmetry from that which their form would seem to indicate, are often traversed by rifts and easily fly to pieces; but this is not the case with mimetic crystals.[1]

Mention may conveniently be made here of another source of change of symmetry closely resembling change produced by dimorphism, but of a very different nature :—

When some of the ties holding the balls of a linked homogeneous assemblage in their places are loosed, while others remain, it may happen that certain of the balls break away from their symmetrically situated positions among the rest which continue linked together as a continuous whole, and if the process takes place uniformly, *i.e.*, symmetrically, and the loose balls pass away, a symmetrical skeleton framework will remain, having interstices or gaps symmetrically disposed.[2]

And we may conceive of such a framework being strained in the process, so that results follow which are anomalous with respect to the degree of symmetry of the unstrained framework.

Or again, we may conceive that the removal of the loosed balls permits the parts of the framework, in obedience to the principle of closest-packing, to adjust themselves to a higher symmetry than that which they were able to attain while these balls were present.

For comparison with these conclusions we may cite the behaviour of *zeolites* when warmed.

Thus, Rinne has shown that these water-holding minerals when heated and treated with oil to get rid of the turbidity which attends the loss of the water, manifest important changes of symmetry without disintegrating.

In some cases, *e.g.*, natrolite, lowering of the symmetry accompanied by twinning take place, the boundaries of the twinning

---

[1] Brauns, *loc. cit.*, p. 2. These latter are, it is suggested, comparable to assemblages of particles which have grown by accretion *after* a dimorphous change to a lower symmetry has taken place, the added parts being therefore free from strain. Comp. pp. 632 and 641.

[2] The highly symmetrical skeleton assemblages thus arrived at are not to be confounded with the grosser sponge-like structures subsequently described which are compared to crystalloids. (See p. 666.)

sections being intimately related to the external form, and thus indicating a connection with strain set up by the change.[1]

In others, in which the zeolite is already twinned, the twinning disappears, and the higher symmetry imitated by it actually obtains as the water is driven out, *e. g.*, in the case of desmine.[2]

Multiple twinning by dimorphous change which involves some relative displacement of the different individuals—Mimetic crystals.

Multiple-twinning of a less symmetrical character is producible as follows :—

In cases of dimorphous change let the shearing and distortion which take place in consequence of the existence of some restraint on change of form in the way above explained, be such as to involve, when completed, a diminution of symmetry so that alternate individuals found ranged about an axis after the change has taken place *do not possess the same orientation of parts.*

The most obvious way for this diminution of symmetry to come about is for the angular dimension of the individuals to change so that they are no longer capable of fitting exactly together around the axis of the nucleus, a condition of strain and ultimate rupture of the altering assemblage being brought about in consequence of the angular dimension of the individuals becoming either too great or too small for them collectively to make out the entire 360° about the axis around which they lie.

The principle of closest-packing will, however, limit the amount of disturbance thus caused so as to make it the least possible, and thus when a compound-twinned nucleus is formed in an assemblage in this way, and the general conditions are regular and favourable, *as many segments or individuals will continue symmetrically related as the change of angular dimensions will admit of, the dislocation being confined to one place or to two places on opposite sides of the axis.*

When a distorted solid nucleus is once formed it is easy to see that regular growth[3] of its various surfaces will perpetuate

---

[1] Math. und naturwiss. Mittheilungen aus den Sitzungsberichten der königlich Akad. der Wissenschaften Berlin, 1890, p. 708.

[2] *Ibid.*, p. 717.   Comp. Brauns, *loc. cit.*, pp. 314–316, and 320.

[3] The regularity need not be so great as that the growth is uniform at any given

alike the symmetry and unsymmetry which characterize the nucleus.

Examples of pseudo-symmetry in which crystals twin in such a way as to ape a higher symmetry than that which they possess, and which strictly resemble the kind of twinning of homogeneous assemblages just shown to be producible, are numerous. The pseudo-hexagonal twin form of cassiterite, and the pseudo-tetragonal form of staurolite may be instanced.

The aping of a higher symmetry by a lower will be likely to be most conspicuous in the case of the existence of two dimorphous forms of the same assemblage in which the distribution of the constituents is much the same,[1] for at some stage of the change of conditions which produces the dimorphism the two compared assemblages may probably have been of nearly or quite the same form.

This reminds us of the familiar case of dimorphism of calcium carbonate which crystallizes in the rhombohedral system as calcite, and in the orthorhombic as aragonite. The prism-angle of the latter is 116° 13′, and when the prism is accompanied by the brachypinacoid the combination has much the same appearance as a hexagonal prism of calcite, of which the angle is 120°. And in this instance the mimicry of the higher symmetry is frequently increased by complicated twinning upon the primary prism.

In some other cases where two dimorphous forms of the same substance are obtainable, a still more remarkable relation exists. Thus the prism angle (70° 32′) of claudetite, the monoclinic form of arsenic trioxide, has the same value as a cubic octahedron angle, *i.e.*, of that angle of arsenolite, the cubic form of the same substance. And a similar relation is presented by the forms of antimony trioxide, which is isodimorphous with arsenic trioxide.[2]

In the preceding cases of twinning of homogeneous assemblages from dimorphous change, a boundary surface separating

---

time at similar surfaces. And to compare with this we have evidence, *e.g.*, in embedded twins such as the Karlsbad twin of orthoclase, that larger faces often grow faster than the smaller ones of the same kind.

[1] See p. 576.

[2] See Pope's Translation of Fock's "Chemische Krystallographie," p. 152, where other similar instances are given.

twin individuals in a nucleus, whatever its development afterwards, is at first a principal plane of each individual, and the networks of centres found in planes parallel to it display the same angles sameways orientated in both individuals. A kind of twinning is, however, conceivable in which this is not the case.

For, if after a twinned nucleus has been produced by a change of external conditions in the way above explained, this change immediately proceeds further, so that the individuals forming the twin seek to pass by distortion to a yet lower kind of symmetry, and the accomplishment of this further change for one individual *would involve a distortion in the separating plane different in direction from the distortion in this plane which would be involved by the corresponding change in the other individual meeting it at this plane,* the following results must be looked for when the twinned nucleus is partly solidified :—

A condition of strain at the separating plane and in its immediate vicinity where the individuals will be mutually restrained from compliance with the demands of the further change of conditions, but, especially in cases where the plane is very small, a rapid approximation to the newly-acquired symmetry, and consequent falling off in strain as we pass away from this plane.

As a consequence of this, two individuals of a twinned nucleus will be more or less contorted near the place of contact, and, where the symmetry with respect to the plane is of a low order, will be also bent. Where there is no bending, a principal plane direction of each individual will still remain parallel to the separating plane, but the angles of the structure of one individual in this plane-direction will cease to be identical in orientation with those of the structure of the other individual. Where there is bending in addition, no principal plane direction of either individual will continue parallel with the separating plane.

Notwithstanding the contortion of the nucleus thus brought about, layers subsequently deposited may be expected to be laid comformably with the homogeneous symmetry reached by the free ends of the individuals, any irregularity of growth caused by the contortion rapidly dying out; the growing individuals will thus extend themselves to meet one another unconformably, so far as internal structure is concerned, as in the case of individual

crystals attached to one another unsymmetrically. Even, however, where there is bending, the relative orientation of the individuals will preserve its symmetrical character, because the distortion of the structure of one individual of the nucleus will be accompanied by the similar distortion of that of the other.

For comparison with examples of the first kind, in which there is no bending, we may mention the Carlsbad twin of orthoclase,[1] and for comparison with the results of twinning accompanied by bending of the nucleus, the anorthic twins of pericline and those of anorthite.

Secondary twinning.

A word may appropriately be said here about an important property of some assemblages whose parts are competent by a mere linear distortion to pass to a different symmetry. This property may be described as follows :—

Besides the kinds of twinning just referred to, another kind of twinning which is also produced by a shear is conceivable, in which, however, the origin of the disturbance of the original equilibrium-arrangement, instead of being found in a dimorphous change, *i. e.*, in an alteration of the relations subsisting between the parts, originates in some external deforming agency, the kind of internal symmetry towards which the system tends in obedience to the principle of closest-packing continuing the same after the disturbance.

This secondary twinning can occur in an assemblage whose parts are so related as to be geometrically competent by a linear distortion, or simple shear, to pass to a different order of symmetry, *in the cases where this different symmetry has a plane of symmetry not found in the undistorted assemblage.*

For where this is the case the return distortion of the derived symmetry, which would eliminate the plane of symmetry and produce the initial arrangement, must be inclined to this plane, and must, therefore, owing to the presence of the latter, be one of a pair of enantiomorphously related distortions equally possible, and the angle between the directions of which is bisected by the

---

[1] See Maskelyne's "Morphology of Crystals," p. 176.

direction of this plane. And these two distortions will, it is evident, owing to the symmetry, affect similarly the system of points lying in the plane of symmetry.

Consequently if one half of an ideal assemblage possessing the derived higher symmetry, lying on one side of the acquired plane of symmetry, experiences one distortion, while the other half experiences the distortion enantiomorphous to it, the points lying in the plane of symmetry will be able to obey both distortions at the same time, *i. e.*, they will be distorted in precisely the same way by each of them.

Therefore, since all planes of points parallel to one another are similarly affected by any uniform linear distortion of an assemblage, every plane of points parallel to the plane of symmetry will experience the same change whichever of the two enantiomorphously related distortions it is subjected to.

Therefore, finally, if those planes of points composing the original assemblage whose plane direction would become that of the plane of symmetry if a distortion to the derived symmetry took place, are capable of sliding on one another, *i. e.*, of undertaking a simple shear in any direction, it follows that twinning of the assemblage can be produced by such a shear if it affects the part of the assemblage lying on one side of some one of the planes of points referred to, and not the part on the other side.

Or, if the movement is accompanied by a slight temporary increase of the distances separating the moving layers, it can equally well take place if the plane separating the half of the assemblage affected by the shear from the other half has instead a certain direction which, when distortion to the derived symmetry has taken place, would be perpendicular to the plane of symmetry. This will be easier to follow in the particular case treated of below.

The shifted portion of the assemblage will be the enantiomorph of the unaltered portion unless these two portions are identical with their own mirror-image, and therefore with one another, when they will merely occupy enantiomorphously similar positions with respect to the separating plane.

The following is an example of a rhombohedral assemblage possessed of the property referred to.

Partition space into equal similar obtuse rhombohedra by drawing three sets of parallel planes in an appropriate manner.

At the points of bisection of all the rhombohedron edges place centres of equal spheres whose magnitude is such that they touch one another.

With their centres at all the rhombohedron angles place a second set of equal spheres of such a radius as to touch the spheres first placed.

Finally, with their centres at all the rhombohedron centres place a third set of equal spheres which are also of such a radius as to touch the spheres first placed.

The spheres at the rhombohedron angles are then each in contact with six spheres; those at the rhombohedron edges, and those at the centres are each also in contact with six.

If we regard such an assemblage as made up of layers of balls lying in planes parallel to the rhombo-hedron faces it is seen that it has the property referred to above, and is capable of distortion to a rhombic form, a face of the rhombohedron be-coming the base of the rhombic prism.

Fig. 19.

The kind of movement is diagram-matically indicated in fig. 19, the shifted portions of each layer being supposed kept in contact with the un-shifted portions of the same layer at one end during the shear. This condition involves a slight temporary separation or widening of the distance between the layers, at least in the neighbourhood of the separating surface of the twins formed.
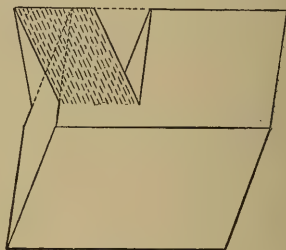
The type of homogeneous structure presented is that numbered $52a_1$ in my list.[1] The generic symmetry is that of Class 12 in Sohncke's list.[2] The three kinds of balls are present in the numerical proportions $1 : 1 : 3$.

The resemblances to the details of the case of the artificial twinning of Iceland spar are here very close, the atoms composing this substance having indeed the numerical proportions referred

---

[1] Zeitschr. für. Kryst., 23, p. 47.   [2] *Ibid.*, 20, p. 461.

to. It is, however, unlikely that we have before us the precise arrangement prevailing in this body, because a division into unit groups of the assemblage in question would necessarily be an arbitrary one on account of the very specialized situations occupied by the balls.

The direction adopted for the shear agrees better with the cleavage direction of Iceland spar than does the one it is usually supposed to take.

If, instead of independent balls we have groups of balls, and the groups have some simple rhombohedral arrangement, *there is still no need to suppose rotation of the groups with respect to the moving planes in which they lie,*[1] provided each of the latter is a plane of symmetry of each of the individual groups which it intersects.

Many peculiarities of crystal growth and of crystal-twinning and grouping are no doubt traceable to the *partial* application or distribution of the *external* forces or conditions of various kinds prevalent during the process of crystallization, *e. g.*, there is sometimes a tendency for a crystal to grow faster in some particular direction when, so far as symmetry is concerned, there are other similarly related directions equally available. All such cases are outside the scope of this investigation, for there are no analogies to peculiarities of this kind in the interactions of the parts of a homogeneous assemblage, these conforming strictly to the symmetry.

Formation of isomorphous assemblages and their intermixture—Resemblances to isomorphous, isogonous, and mixed crystals, and to crystalloids,[2] *also to some kinds of diffusion.*

A few words will now be said as to the nature of the likeness of their parts and their conditions which will cause two homogeneous assemblages, composed wholly or in part of different constituents, whether groups are present or not, when in equilibrium—(*a*) *to have corresponding angles between planes of centres*

---

[1] In the usually received explanation of the nature of the artificial twinning of Iceland spar, rotation of the molecules is resorted to; this is unnecessary, *all that is requisite is change of orientation of their situation relatively to the assemblage,* and this, in the case referred to, is accomplished by the simple shear.

[2] See note 1, p. 620.

equal, i.e., *to be isomorphous or isogonous;* [1] (*b*) *in addition to this to be capable of being intercalated in such a way that variously-shaped masses of the two assemblages have their corresponding planes of centres similarly orientated.*

We have already distinguished *operative* from *inoperative* balls in an assemblage,[2] operative balls being those on which the general form of the assemblage depends, and inoperative balls those which lie between the operative ones without doing anything towards regulating the relative situations of the latter. Bearing this in mind, the following proposition is evident:—

If in two different assemblages the operative balls are the same, and, where more kinds than one are found, are present in the same proportions, the arrangement of the operative balls will, *if the conditions are the same,* be identical in both assemblages, and, unless a difference in the arrangement of the inoperative ones sufficient to produce a difference in the generic symmetry exists, the two assemblages will be completely isomorphous.[3] They will also be capable of being intercalated in any proportions without any lessening of the closeness of packing. The inoperative balls may obviously be either entirely or partially different in the two assemblages.

Far less resemblance than is here postulated will, however, suffice to make two assemblages practically isomorphous, and far less will too suffice to make them capable of becoming intercalated in such a way that the masses of different kinds have their corresponding planes of centres similarly orientated.

For, on the one hand, they will be practically isomorphous if the inclinations of the planes of centres to one another in one assemblage be the same as the inclinations of corresponding planes to one another in the other assemblage, and that even

---

[1] The term isomorphous is sometimes applied to two crystals when one has hemihedral or tetartohedral symmetry and the other has not, *so long as all corresponding angles are the same: e. g.,* dolomite and calcite. Compare Groth's " Physikalische Krystallographie," p. 278. The term isogonism has been suggested to cover cases in which the resemblance is incomplete and only extends to some of the crystal zones. See Fock's " Chemical Crystallography," Pope's translation, p. 167.

[2] See p. 547.

[3] Thus, as Dumas puts it, one may in a building substitute one stone for another, and yet the building may retain its form and general properties.

if the arrangement of the balls and the linear dimensions are different.

On the other hand, they will be capable of the kind of intercalation referred to, if in a roughly intermingled collection of two different kinds of assemblage, where both are about to solidify, it is found that at boundaries between the different kinds very close packing indeed is attained when the two adjacent structures are similarly orientated. For if this is so a bounding plane-layer of the growing solid composed of the one assemblage is capable of receiving an accretion either of another layer of the same kind of assemblage, *or of a suitable layer of the other assemblage.*

If two intercalated assemblages are so related as to be capable of subdivision into space-units[1] which are identically shaped or very nearly so, or indeed if the shape and size of an aggregate formed of a finite number of contiguous space-units of some kind of one assemblage are identical with the shape and size of an aggregate formed by the same or some other finite number of contiguous space-units of some kind in the other assemblage, it is evident that there may be extremely little disturbance of regularity at *all* the boundaries between the two kinds.

If, however, while accretion of one kind of assemblage on the other readily takes place *over small portions of some of the bounding surfaces of the growing solid, the space-units are not congruent,* and this will generally be the case, it is evident that the regularity at the boundaries between the different kinds will be merely an initial one, *i.e.,* found only at the points at which the accretion of one kind on the other makes a fresh start, and that, like the surfaces between the differently orientated individual assemblages of a mass solidified before the arranging sought to be accomplished by the principle of closest-packing is completed,[2] or the more or less irregular surfaces at which in most cases individual twin-assemblages meet *during the continuance of their growth,*[3] the boundary formed as two assemblages of different kinds grow side by side will be a surface of some kind *where they meet unconformably. Nevertheless this want of congruence at some boundaries will be quite consistent with the property that all corresponding directions in the two*

---

[1] See note 1, p. 586. [2] See p. 620. [3] See p. 623.

kinds of assemblages display similar orientation. There will, no doubt, in such a case be some mutual local accommodation of the arrangements of the parts of the assemblages where the two kinds meet, but this will not be likely to disturb parallelism of the contact layers.

Not only isomorphous assemblages but also assemblages displaying less similarity, provided they contain similar planes of centres which will fit sufficiently well together to pack very closely, may become intercalated in a more or less symmetrical manner if the conditions of solidification are favourable, but we see that with a less correspondence of parts than is requisite for isomorphism the symmetry, except in cases of slight admixture, will be greatly deteriorated, and probably in few cases will there be uniformity of orientation of all the distinct fragments of the same kind of assemblage throughout any considerable space.[1]

For two assemblages to be absolutely isomorphous as a consequence of partial identity of composition,[2] it is not necessary for their like parts to behave *identically* under the same exernal conditions, the corresponding balls need not be precisely the same, it is only necessary that the operative statical system of interacting parts in the one assemblage, or some symmetrical system equivalent to it, shall bear the same proportions as those in the other assemblage do, so as to make corresponding angles the same in the two equilibrium arrangements. This is a much less specialized condition for isomorphism than the one stated first.

It is important to notice that the equality of corresponding angles just referred to may be associated with the exhibition of different types of symmetry. For this will be the case if in two assemblages in which the distances in three principal directions between the principal singular points[3] bear the same ratios in

---

[1] There may, however, occasionally be enclosure of a large number of isolated fragments, and perhaps of a continuous mass, of the one assemblage within a continuous mass of the other assemblage throughout which uniformity of orientation prevails. Compare note 1, p. 631.

[2] Cases of isomorphism may arise from fortuitous relationship between the different sets of principal or singular points found in different assemblages, but these, which will necessarily be of very infrequent occurrence, will not be considered here.

[3] See note 1, p. 627.

both,[1] *the positions occupied by single balls or by the centres of highly symmetrical groups of balls in one assemblage are occupied in the other by groups whose type of symmetry is low enough to impose a lower symmetry on the latter assemblage.*

Suppose, for example, to take a very simple case, that in two homogeneous isomorphous assemblages the singular points have the same relative arrangement, both containing balls of a certain kind situated at the centres of equal regular hexagonal right prisms of a particular pattern filling space in the most symmetrical manner possible, but that while in the one assemblage the remaining balls consist of triads of another kind of ball with their centre-points at the points in which six prism corners meet, in the other assemblage they consist of right tetragonal groups each composed of four balls of a third kind with the group centres placed in the same way as those of the triads.[2]

It is then manifest that if the principle of closest-packing requires the groups to be orientated in the most symmetrical way possible, the inclinations of the principal planes of points to one another will be the same in the two assemblages, which will be capable of intercalation in any proportions, but that the symmetry of the one containing the triads will be of a higher class than that of the other, the former having the symmetry of type $25a_1$, the latter that of type $23b_1$, in my tables of homogeneous structures.[3]

The isomorphism displayed by two allied assemblages will commonly not be perfect if the balls which are unlike in them are not absolutely inoperative in the sense above defined; and whether they are so or not, if the balls common to both do not behave identically under the same external conditions, but are of different magnitude[4] according to the nature of the balls with which they are associated in the two cases, it is very unlikely that the equality of corresponding angles will, except in the regular system, be

---

[1] The ratios referred to appear to be the same as what are called by Tutton " distance ratios,'' by Muthmann " topic '' or " topical axial ratios.'' See Zeitschr. für Kryst., 22, p. 497, and Journ. Chem. Soc., vol. lxv., p. 628. We see that for their determination it is *not* necessary to partition homogeneous structures in any way.

[2] Neither arrangement is capable of being so linked as to form groups of a single kind without deteriorating the symmetry. It would, of course, be easy to instance others which are capable.

[3] Zeitschr. f. Kryst, 23, pp. 45 and 52.   [4] See page 529.

absolute ; there will be some difference in the conditions of equilibrium because the changes in the operative balls brought about by the substitution of one set of inoperative balls for another are not strictly proportionate.[1]

If the presence of the balls which differ in two assemblages whose composition is partially the same, effects *any material alteration* in the conditions to which the similar balls are exposed so as to make them behave quite differently in the two assemblages, isomorphism will manifestly not be producible by the similarity of these balls. In other words, there must be enough resemblance between the unlike balls to preclude them from disturbing the similarity of conditions requisite to the like balls that they may behave sufficiently alike in the two cases.

If, owing to some difference in the conditions of equilibrium of two identical assemblages they are dimorphs, or if two assemblages capable under certain conditions of isomorphism or partial isomorphism and intercalation, as just explained, are subject to conditions in which similarity of arrangement of their principal centres or singular points does not prevail, it is evident that certain layers may still display identity or similarity of arrangement in the two assemblages and cause the inclination of some principal directions to be the same in both, producing isogonism or partial correspondence less complete than that above denominated isomorphism, but of the same character.

And with reference to the intercalation of similarly-orientated isomorphous assemblages :—

Where the supply of material present at a growing surface is of various sorts it is evident that *the average proportions in which the constituents of different kinds are added will depend, not only on the proportions in which they occur in the supply, but also on the relative rates at which the different kinds are prepared to solidify at any given point.* If one kind can assume tranquillity more readily than another we shall expect the accretion of the former kind to be thereby promoted.

As the mixing of two or more kinds in the same layer may in

---

[1] This is perhaps expressed more clearly if, instead of balls of different sizes, we speak of mutually repellent particles of different kinds (see note 3, p. 530).

many cases be a hindrance to tranquillity, there will probably be a tendency to form distinct layers of each kind, the growing portion at any point remaining disturbed, and therefore unsolidified, till the more or less fortuitous movements taking place have resulted in perfecting the uniformity of the layer.

So long as the proportions of the different assemblages present in the unsolidified mass are unaltered, and the conditions remain the same, an average uniformity of composition, or general homogeneity of the growing mixed solid should result; if, on the other hand, the proportions, or the conditions, or both change gradually, a gradual change of average composition may be expected to occur.

Where the fitting together of the corresponding planes of balls of the *different* assemblages produces less closeness of packing than the fitting together of the planes of balls of one of the assemblages taken alone, it is evident that retardation of solidification will tend, by giving additional time for the carrying out of the arranging process, to diminish the number of *separate* fragments of the two assemblages and increase their size, and indeed ultimately to cause them to mass themselves separately.

The facts with regard to isomorphous crystals bear a close resemblance to the properties of isomorphous assemblages which have just been deduced.

Thus in the large majority of cases isomorphs have a similar chemical constitution[1] and a large proportion of common constituents. And the constituents in which they differ have in general similar properties and appear to exercise a similar influence on the common constituents.[2]

The isomorphism of crystals is seldom, if ever, absolute, so that when accurate measurements of corresponding angles are made differences are revealed, the amounts of which are ordinarily

---

[1] Fock's "Einleitung in die chemische Krystallographie," p. 65; or Enlarged English translation of same work (Pope), p. 93.

[2] Comp. Mischerlich's definition "that only those substances are to be designated isomorphous which possess, in addition to an analogous chemical composition, a similar crystal form, and which crystallize together in variable proportions."

The equality of molecular volume of isomorphous compounds so commonly observed will naturally be traced to the similar influence exerted by the allied though different constituents.

of the same order as the chemical differences between the substances compared. In the systems of low symmetry, these differences are not generally of such a simple character as those which appear when a body is subjected to a single linear distortion, they are traceable to slight differences in the dimensions in different directions of the space-lattices formed by the most symmetrical singular points or centres in the respective isomorphs.[1] They are ordinarily most evident in a certain principal zone, whilst between the corresponding angles of other zones nearly perpendicular thereto practically-complete identity subsists.[2]

It is generally the case that the similarity of form is greater the nearer the compared bodies are related chemically.

As we should expect from the similarity of form, and the capacity to crystallize together, isomorphous crystals commonly have similar cleavage. This similarity can scarcely be appealed to as throwing any additional light on the matter, but it is perhaps significant that the correspondence is not particularly great in some cases, *e.g.*, when we compare aragonite, strontianite, cerusite, and witherite; the occasional occurrence of such divergences is to be anticipated if the constituents which differ occupy definite situations in the structure. The more or less considerable dissimilarity of the etched figures on isomorphous crystals[3] would seem to point the same way; for it is easy to see, and indeed to show experimentally, that if two *similarly arranged* homogeneous structures be built up of different mixed materials in such a way as to give great differences of the same property, cohesion, pyroelectricity, or some other, in different directions in the same structure, the materials can be so selected and the common arrangement have such a configuration as to give widely-diverse sets of directional relations in the two systems, notwithstanding that the arrangement is the same in both.

A very similar line of argument may be adopted with reference

[1] See note 1, p. 651.

[2] Fock's " Einleitung in die chemische Krystallographie," p. 65; or Pope's translation of same, p. 92.

[3] A case of great dissimilarity is given in Pope's translation of Fock's " Chemische Krystallographie," p. 102.

Cases in which the dissimilarity of the etched figures is such as to place the crystals in a different class of symmetry are referred to presently.

to the often great want of correspondence between the optical properties of two isomorphous crystals.[1]

The fact that the densities of isomorphous mixtures are weighted-means of the densities of their constituents militates against the supposition that there is any change in the relation of the parts of these constituents such as would alter properties; whatever change exists, the parts of a chemical molecule which enters into a mixture must be supposed to persist and perform the same functions as they do when unmixed.[2]

Perhaps the evidence which most strongly supports the view that the dissimilar constituents in two isomorphous bodies occupy definite similar situations, being symmetrically and regularly interspersed each throughout the compound of which it is a constituent in a similar manner, is afforded by the valuable researches of Tutton.

This resourceful and original investigator has made a series of measurements of the isomorphous crystals of the monosymmetrical double sulphates of the composition $R_2 SO_4, R'' SO_4, 6H_2O$. Each of the 22 salts measured contains, as the metal R, one of the three alkali metals—potassium, rubidim, or caesium; the salts may hence be arranged in series of three, containing the same dyad metal R'', but different monad ones. The measurements show that all the geometrical properties of the rubidium salts are intermediate between the corresponding properties of the potassium and caesium salts respectively. The same is also true of the facility of crystallization and the crystalline habit assumed by the rubidium salts. Since the axial angles of the rubidium salts are very approximately a mean between the corresponding ones of potassium and caesium, and the same relation approximately subsists between the atomic weights, the probability suggests itself that the differences observed in the properties are due to the sur-

---

[1] Comp. Tutton. Journ. Chem. Soc., 1894, p. 628.

[2] See Retgers on the specific weight of isomorphous mixtures. Zeitschr. f. physikal. Chemie, vol. iii., p. 497. Similar relations subsist for other properties. Comp. Brauns' "Optische Anomalien der Krystalle," p. 205. This author notes, too, that mixed crystals whose constituents when crystallized alone give, the one negative, the other positive crystals, can contain such proportions of the two constituents as to be isotropic. *Ib.*, p. 237.

vival of some property or properties of the respective elements in the compounds into which they enter.[1]

Mixtures of the monoclinic and anorthic felspars furnish striking examples of the crystallizing together, in what must be regarded as isomorphous mixtures, of substances belonging to different crystal systems; and the extremely close resemblances which compounds may display and yet be of different systems is yet more strikingly exemplified by the arsenious and antimonious oxides, which, until a few years ago, were regarded as furnishing an exceptionally good example of an isodimorphous group with crystal form and cleavage practically identical. The latter compounds have been shown by des Cloizeaux to belong to different crystal systems.[2]

To compare with our conclusion that assemblages which are not isomorphous, but which are nevertheless capable of *quasi* homogeneous intercalation, may exist, we have the fact that in recent years a number of substances have become known which are not chemically analogous, and do not possess isomorphous forms, but which yet form homogeneous solid solutions.[3]

The following are some other less-conspicuous properties of isormorphous homogeneous assemblages to which observed phenomena furnish resemblances.

We may have two assemblages whose composition is such, that when exposed to similar conditions of a certain kind they are isomorphous, but which under another set of conditions attain equilbrium in different symmetries, one or both of the assemblages being therefore dimorphous. And since we have already concluded that an assemblage, if sufficiently near a critical point, may have its symmetry determined by the symmetry of a small solidified portion of similar composition which comes in contact with it,[4] we see that in a rough mixture of the two assemblages the *order* in which the two kinds *commence* to solidify may suffice to determine whether they shall be isomorphous and crystallize together or not.

---

[1] Journ. Chem. Soc., 1893, p. 337; or Zeitschr. f. Kryst., 21, p. 491, &c.; also Journ. Chem. Soc., 1894, p. 628; or Zeitschr. f. Kryst., 24. p. 1.

[2] Bull. Min., vol. x., p. 303, 1887.

[3] Pope's translation of Fock's "Chemische Krystallographie," p. 141.

[4] See pp. 576 and 581.

And again, if the properties of an assemblage are influenced by the mere presence of another assemblage intermixed with it, the priority in crystallization of one of the assemblages, which has just been referred to, *may depend on the proportions in which they are roughly intermixed*, or the same cause may in some other way determine which of two dimorphous forms one of them shall assume, and consequently whether they shall be isomorphous or not.

It has just been said that the proportions in which the constituents of different kinds are added to a solid surface growing in a mixed collection of isomorphous assemblages, will depend, not only on the proportions in which they occur in the mixture, but also on the relative rates at which the different kinds of assemblage are prepared to solidify at any given point. It may be added that the greater any discrepancy of form between two assemblages which are nevertheless practically isomorphous and capable of close-packed intercalation as above explained, the more subject to fluctuation will be the conditions of solidification of a mixed mass of them as the proportions of the two kinds present are changed.

For we have already concluded that in a solidifying assemblage the place of maximum tranquillity is the place of readiest solidification,[1] and if the assemblages intercalated do not fit together very well, the places of their junction will be places of less tranquillity, and the effect of these on each kind of assemblage present will vary according to the proportions in which they occur.

Suppose that we take a series of mixtures composed of different proportions of two isomorphous assemblages which are capable of solidifying together, but between whose forms there is some considerable discrepancy, the series being arranged so that succeeding terms contain more and more of one constituent, and less and less of the other, one assemblage unmixed standing at one end of the series, and the other assemblage also unmixed standing at the other end.

It is then evident that when we examine the behaviour of the combinations forming such a series near the solidifying point, we can discriminate at least two classes of cases :—

---

[1] See pp. 565 and 623.

1. Cases in which the influence of one assemblage A on the general symmetry of disposition of the constituents of the mixed solid is predominant, these cases lying together at one end of the series.

2. Cases in which the influence of the other assemblage B is thus predominant, these cases lying at the other end of the series.

Now it is conceivable that if the discrepancy between the two constituent assemblages thus capable of intermixture is sufficiently great, the necessity for closest-packing will require one or other assemblage to predominate locally in the solidifying mass. For where there is such a discrepancy there will be a struggle in the mixed solidifying mass between its constituents, each seeking to impose on the mass the arrangement proper to itself when unmixed, and the result will be that that form of arrangement which gains the upper hand will greatly favour the accretion of the constituent having this arrangement in preference to the other constituent, and will thus ensure a considerable preponderance of it throughout those portions of the mass in which it is thus in the ascendant.

In such a case we must not look, as we pass along the series referred to, for a group of terms lying between the two classes named, and which belong to neither of them, but for a group of terms in which both classes appear side by side, one compensating the other, the liquid mixtures from which this group is formed being on the one hand richer in kind B than is the limiting case, with its maximum quantity of B, of those which furnish solely the symmetrical form dictated by A, and on the other hand richer in kind A than is the limiting case, with its maximum quantity of A, of those which give solely the form dictated by B. We shall not, of course, expect these limiting solid combinations to contain *similar* though opposite proportions of the two assemblages; it may be much easier for A to solidify than for B.

The series of differently proportioned solid mixtures formed from such a series of liquid mixtures will in such a case contain a gap extending from the term with the greatest proportion of B capable of being contained in a mixed solid which has the general form of A, to the term with the greatest proportion of A capable of being contained in a mixed solid which has the general form of B.

The above corresponds extremely well with the facts concerning a series of isomorphous mixtures of the chlorates of potassium and thallium completely investigated by Bakhuis Roozeboom.[1]

Both these substances crystallize in the monosymmetric system, possess similar crystalline forms, and give rise to isomorphous mixtures, not however in all proportions. The following table gives the experimental results :—

No. of Experiment.	One litre of solution contains				$c_1 + c_2$	$y = \dfrac{c_2}{c_1 + c_2}$	Molecular percentage of $KClO_3$ in the mixed crystals.
	Grams of		Miligram molecules of				
	$TlClO_3$	$KClO_3$	$TlClO_3$ c_1	$KClO_3$ c_2			
1	25·637	—	89·14	—	89·14	0	0
2	19·637	6·884	68·27	56·15	124·42	45·13	2·00
3	12·001	26·100	41·73	212·89	254·62	83·61	12·61
4	9·036	40·064	31·42	326·79	358·21	91·23	25·01
5	7·885	46·497	27·42	379·26	406·68	93·26 ⎫	36·30 and
6	7·935	46·535	27·60	379·57	407·17	93·22 ⎭	97·93
7	6·706	46·410	23·32	378·55	401·87	94·20	99·28
8	6·723	47·109	23·37	384·25	407·62	94·27	99·60
9	4·858	47·312	16·89	385·91	402·80	95·81	99·62
10	2·769	47·134	9·63	384·46	394·09	97·56	99·67
11	—	49·925	—	407·22	407·22	100·00	100·00

Experiments 1 and 11 were made with solutions of the pure salts. The mixtures deposited in experiments 7–10 were scale-shaped crystals similar in appearance to those of potassium chlorate; experiments 2–4 yielded much smaller, acicular crystals resembling those of thallium chlorate. Both kinds of crystals were obtained side by side in experiment 5; after removing them, and allowing the

[1] Zeitschr. für physik. Chemie, vol. viii., p. 531. Compare also, for other cases in which two kinds of mixed crystals are deposited by a mixed solution, Rammelsberg's observations published in Poggendorf's Annalen XCI., p. 321; and also Retger's observations in Zeitschr. f. physik. Chem., vol. iii., p. 542.

mother liquor to evaporate the same two kinds of crystals separated and the solution preserved its composition unchanged as is shown by No. 6. Such behaviour is, however, only possible if the deposited crystals have the same average composition as the dissolved matter.[1]

In connection with the argument here submitted that the conditions competent to produce isomorphism and intercalation of similarly-orientated homogeneous assemblages are so little specialized, it is interesting to notice that during recent years a considerable number of examples have been recorded of substances which form isomorphous mixtures, but are at the same time very slightly, or not at all related in a chemical sense.[2]

It is conceivable that in some cases one of two kinds of assemblages entering into a series of intercalated mixtures may always, whatever the proportions in which the assemblages are intermixed, *take the lead in solidifying*, and when this is the case, and there is some small discrepancy between the forms of internal symmetry of the two assemblages, which may or may not affect the angles between the planes of centres, we may find that the assemblage which thus takes the lead causes some modification of the form of the other assemblage, the latter accommodating its symmetry to that of the earlier solidified one to which it attaches itself.

The entire mixture of assemblages will, in such a case, as to some of its properties, present a resemblance to the kind of assemblage which thus takes the lead.

In this connection a case may be mentioned in which the optical properties of a mixed crystal resemble those of one of the constituents only, thus furnishing an exception to the laws of Mallard and Dufet. The tartrates of ammonium and thallium are completely isomorphous, both belong to the mono-symmetric system, show nearly identical angles, and crystallize together in all proportions. The ammonium salt has a cleavage parallel to the basal plane, the optic axes lie in the plane of symmetry, and the optic axial angle is 42° 38′. The thallium salt, on the other hand, shows no cleavage, the optic axial plane is perpendicular to the

---

[1] Pope's translation of Fock's " Chemical Crystallography," p. 121.

[2] *Ibid.*, p. 131.

plane of symmetry, and the axial angle is $59\frac{1}{2}°$. The isomorphous mixture of the two salts, however, invariably show the same cleavage and optic axial plane as the ammonium salt; a mixture containing 88·7 per cent. of the thallium salt was, moreover, obtained, in which the optic axial angle was found to be 43° 31′, being thus completely identical with that of the pure ammonium salt.[1]

A resemblance of a lower order than isomorphism is conceivable between assemblages which have some constituents the same and similarly arranged or grouped in both. For although the congruence may not be adequate to produce equality of all corresponding angles or any intercalation, the arrangement may be so far alike in both as to come under the same type of symmetry and to have some axial lengths in one equal to some in the other.

An illustration will, perhaps, make this plainer :—Suppose that an assemblage, when closest-packed, is found with its unit-groups arranged in rhombic symmetry in parallel layers in such a way that when it is partitioned symmetrically in the simplest manner possible, the cells are right-rhombic prisms, each containing a unit-group.

And suppose that a second assemblage is composed of unit-groups, each of which consists of the same constituents arranged in the same manner as in the first-named groups, and in addition to these some other constituents; the portion of a group which is the same forming the larger part of it, and the additional constituents being placed at opposite ends of the group.

It is then conceivable that the second assemblage when closest-packed will also be capable of symmetrical partitioning into cells which are right-rhombic prisms, and that the only difference between the partitioning of the first and that of the second assemblage will be that the prismatic cells of the latter will be rather longer than those of the former, the cross sections being identical.

In such a case there will be a remarkable morphotropic relationship between the assemblages, for two out of the three axial directions will furnish the same values in both, and so consequently will the zone containing these two directions.

---

[1] See Wyrouboff's researches in Zeitchr. f. Kryst, 13, p. 648 ; also Pope's translation of Fock's " Introduction to Chemical Crystallography," p. 138.

To compare with the above we have the very remarkable resemblances obtaining between a new addition-compound of camphoric acid with acetone and camphoric anhydride, which have been traced by Pope.[1] Both crystallize in the ortho-rhombic system and display the same axial values in two directions, while they differ as to the third : the cleavages too, the planes of which belong to the zone throughout which the angular values are the same in both, correspond very closely, and so do the optical characters and the face-markings on the crystals.

The kind of relation just referred to is very suggestive in connection with homologous series of carbon compounds, it being possible to form series of groupings of balls, each term of which is derived from the previous term by adding balls symmetrically at the end so as to elongate the group without altering its general character. The fitting of similar groups together side by side, as well as many features of the groups taken individually, will be found to furnish great similarities if the different types forming such a series are taken successively, and the geometrical features compared.

If only one, or a few of the equivalent atoms in a compound are replaced by others, the crystalline system generally changes, and usually in such a way that the new system possesses less symmetry than the old. The influence of substitution on the crystalline form of benzene and its derivatives has been the most completely investigated.

In the case of substitution of hydroxl- or nitro- groups for hydrogen atoms in the benzene molecule the length of only one axis changes considerably, those of the two others remaining practically constant.[2]

In connection with the consideration of the effects of partial similarity of composition and grouping on the general symmetry of an assemblage, it is *very important to observe* that groups are conceivable in which a high symmetry would be presented were it not for some slight defect in form or arrangement, *and it is evident that, in the case of such groups, closest-packing may be attained by the*

---

[1] Transactions Chemical Soc., 1896, p. 1696.

[2] Pope's translation of Fock's "Chemische Krystallographie," p. 176. Comp. Groth's Zeitschr. f. Kyrst., 8. p. 284. Comp. also *ante*, p. 619.

formation of an assemblage which treats this slight deformity as non-existent.

To make this plainer by means of an example :—Suppose that a linked group has cubic symmetry, except that out of twenty-four outermost balls but twenty-two or twenty-three are similar and similarly situated, dissimilar balls making up the twenty-four and occupying places which are symmetrically situated, or nearly so ; it is then conceivable that the closest-packing of a number of groups of this description may be one which disregards the slight irregularity and puts the groups together with their centres at the points of a cubic lattice, and with their predominating symmetrically arranged balls forming, as far as they go, a system in cubic symmetry.

In a case of this kind the positions of the irregularities will not be symmetrically distributed ; in other words the groups, when the deformities are taken into account, will be found variously orientated and the assemblage will not be strictly—*i. e.*, mathematically—homogeneous, although, owing to the average effect of the deformities being the same in corresponding directions, the general symmetry will not be appreciably impaired.

Large groups will be more particularly liable to function as though of a higher symmetry than they actually possess in the way just described.

To compare with this we have the observation frequently made with reference to carbon compounds and their derivatives, that the higher the symmetry of the parent substance the less is the change in crystalline form caused by substitution. Thus the cubic form of ammonium alum is unaffected by the entrance of a methyl group in place of an atom of ammoniacal hydrogen, whilst such a substitution in an orthorhombic or monosymmetric compound would lead to a considerable alteration in crystalline form. If the parent substance contains several equivalent hydrogen atoms, it not infrequently happens that the symmetry of the system is decreased by substitution for one of these atoms; but that, as several or all of the hydrogen atoms are displaced, the products again crystallize in the same system as the parent substance.[1]

---

[1] See Pope's translation of Fock's " Chemische Krystallographie," p. 181.

Including the departure from strict homogeneity just referred to, we have now dealt with *four* distinct ways in which assemblages may fail in homogeneity and yet exhibit a related orientation and symmetry of their parts, such as are found in crystals.   They are :—

1. A want of uniformity in the arrangement of the inoperative constituents which does not extend to the operative ones, the latter, when taken alone, displaying homogeneity of arrangement.[1]

2. A bending or twisting of thin assemblages whose parts are so related that they pack closer when thus curved than they do when homogeneously placed.[2]

3. A more or less irregular intercalation of two different congruent or partially congruent assemblages, in which, however, one or both preserve the same orientation of corresponding parts.[3]

4. A lack of symmetry in the unit-groups composing an assemblage which is not sufficient to prevent them from performing the same functions as would the more symmetrically-shaped groups which they nearly resemble.   To make the assemblage perfectly homogeneous it would, therefore, merely be requisite to correct these slight departures from regularity without changing the rest of the structure.   The positions of the defects with respect to the group-centres present a haphazard variety within the limits prescribed by the arrangement of the perfect portions of the assemblage.

The intercalation of differently-constituted fragments of homogeneous assemblages in the ways above described will, obviously, be likely in many cases to modify the effect of change of conditions.   Thus it is obvious that if, under change of temperature, one constituent does not change its bulk at the same rate as the other, a condition of strain must be looked for in the mixture which is not found in either constituent taken alone, and that the effects of this strain will, so far as the qualities of the constituents are concerned, be anomalous and not to be accounted for by any addition or subtraction of their individual properties.

To compare with this we may mention the observation of Brauns that while pure crystals of alum, lead nitrate, and barium

---

[1] See p. 548.   [2] See p. 568.   [3] See p. 649.

nitrate are always isotropic, the crystals of these substances which contain isomorphous admixtures are double refracting.[1]

Also the fact that a small addition of ammonia alum to potash alum develops optical properties in the mixture which are wanting in the pure substances ; in particular lamellar polarization investigated by Biot.

It should also be noted that the nitrates, which are double-refracting and are mixed crystals, fly into small pieces when subjected to pressure, but that the isotropic pure crystals are not nearly so brittle.[2]

Finally, we have the important fact that the behaviour of mixed crystals when subjected to change of temperature resembles that of cooled glass,[3] and can also be closely imitated with gelatine models,[4] strong evidence being afforded in this way that the effect is one proceeding from strain.[5]

There are cases in which bodies are mixed crystals and also contain water of crystallization,[6] and any optical anomalies which they display may, therefore, be connected with either or both of these properties according to the conditions prevailing when the observation is made.

The intimate relation between external form and anomalous optical properties which is probably traceable to strain, comes out prominently in the garnets which, as a rule, are mixed crystals composed of several related compounds.[7]

---

[1] Brauns, " Optische Anomalien," p. 50.   Neues Jahrbuch, 1885, I., pp. 96–118. Comp. also Brauns, *loc. cit.*, p. 206.

[2] Brauns, *loc. cit.*, p. 225.   As to sudden fracturing during growth of mixed crystals, see *Ibid.*, 255.

[3] Brauns, *loc. cit.*, p. 224.

[4] In particular such an imitation has been produced by Klocke, Klein and Ben Saude, see *Ibid.*, p. 256.

[5] *Ibid.*, p. 257 ; and, in particular, see also Lehmann's "Molecular Physik," I., p. 450.

[6] *Ibid.*, pp. 240, 340.   Comp. p. 640 above.

[7] *Ibid.*, pp. 245, 251, 253, also 357.

*Intercalated symmetrically-joined assemblages, of which one is liquid
    while the other is linked into a continuous whole.   Comparison
    to crystalloids[1] and colloids.*

Of two assemblages which are mutually intercalated with con-
gruent boundaries, in the way above described,[2] it is conceivable
that one may be liquid, *i.e.*, may be lying in small unlinked
patches among patches of the other which are linked together, and
this may have come about in one of the following two different
ways :—(*a*) The assemblage which does not solidify may have
reached a sufficiently tranquil homogeneous condition to enable it
to fit in symmetrically with patches of the other assemblage, while
the latter arranges itself more or less symmetrically as the con-
ditions admit and solidifies, growing by accretion in the ordinary
way ;[3] or (*b*) The solidification of both intercalated assemblages
may take place as the mass grows, and liquefaction of one of them
may be a subsequent occurrence.   In either case a sponge-like
structure is obtained.[4]

If the two assemblages are isomorphous, so that in becoming
intercalated they can each preserve their continuity of symmetrical
arrangement, *and present the same orientation of their corresponding
structures*, they will, like the more regular of the combinations
above described, in which both constituent-assemblages are solid,
*have corresponding planes of particles similarly orientated in the two
assemblages*.

Since one of the constituents is liquid the mass will display
some of the properties of a liquid,[5] while the existence of the solid
constituent will impart to it some of the characteristics of a
solid.

When from a mass thus constituted some of the tranquil liquid
assemblage is, by degrees, abstracted, the solid skeleton framework

---

[1] See Note 1, p. 620.   [2] See p. 649.   [3] See p. 566.

[4] Since these pages were written the author's attention has been directed to the
experiments made by Bütschli, which support the view that substances which display
imbibition have a cellular or sponge-like structure.   See O. Bütschli: "Ueber den
Bau quellbarer Körper und die Bedingungen der Quellung."   Abhandl. der Gesellsc.
der Wiss. zu Göttingen, 1896.   Bd. xi.

[5] Comp. p. 682.

of the other assemblage will be squeezed together, and some considerable disturbance of the symmetrical arrangement of the parts will ensue, because the constituents forming the framework through being linked together are unable to alter their relative situations sufficiently to produce a fresh homogeneous arrangement; in other words, the symmetry of the framework will have to suffer distortion. The general distribution and the general outlines of the mass will, however, continue of much the same kind and form.

If the mass before the abstraction of some of the liquid portion displays anisotropic properties, the diminution of internal regularity caused by this change will impair these properties, anisotropism requiring uniformity of the conditions at corresponding points, *i.e.*, at points which in the unaltered structure have similar surroundings similarly orientated.

With regard to any change in the general form arising from the same cause, the maximum distortion will be found at the outer boundaries, because there the conditions around a given point are least symmetrical owing to the absence of ties in one direction; it will diminish inwards and at the centre will be a minimum.

Again, if before the withdrawal of the removable portion parallel layers of the linked portion are found in which none of the former is contained, so that these layers are unchanged by the process, it is evident that the crushing together will almost certainly be less in the direction of these planes than in other directions.

Finally if the portions which have been removed, or portions of a similar assemblage, be supplied to a shrunken framework[1] we shall expect the advent of these constituents to restore the linked framework to its primitive condition, and therefore rather to increase than to diminish the symmetry, and if anisotropism is present, to intensify it.

There is considerable resemblance between the properties thus traced and the behaviour of crystalloids.

---

[1] The way in which the loose particles penetrate the shrunken assemblage is referred to in a subsequent section.

Thus these bodies allow the liquid which they absorb to behave within them much as it does when outside.[1]

They are not quite homogeneous but show some difference of constitution as we pass from the centre to the outer boundaries. This is made apparent by the remarkable fact that the crystalloid when placed in a solvent begins to dissolve at its centre, at which a vacuole is formed which gradually grows in size till only the edges of the crystalloid remain undissolved.[2]

Further, while to the superficial observer they often appear quite as regular as crystals, angles of these bodies which according to the law of zones should be equal, differ by several degrees, and the angles vary according to the nature of the medium in which the crystalloids lie.[3]

The double-refraction of crystalloids is always very slight.[4]

Crystalloids not already saturated show imbibition; placed in certain liquids they swell up to a bulk which is many times as great as that they have in their dried condition, and they do this without losing their regular form.[5]

In some cases the extension takes place in a certain direction, but not in directions at right angles to this. Thus in the case of crystalloids of Brazil nuts there is no appreciable increase of dimension perpendicular to the principal axis, and maximum extension takes place in the direction of this axis.[6]

Partial destruction of symmetry of arrangement by the action of an acid is revealed by the fact that too high a proportion of acid produces convexity of the faces of some crystalloids.[7] Also by the fact that crystalloids of Brazil nuts through imbibition of an acid suffer important modification and become incapable of restoration to the form and magnitude they had prior to imbibi-

---

[1] Lothar Meyer says: "It is very noteworthy that in many cases precisely the same phenomena can occur in the interior of the liquid taken up as in that remaining outside, for example, the same diffusion movements. (Lothar Meyer's "Grundzüge der theoretischen Chemie." 2nd Edition, p. 119.) Bedson & Williams' translation, p. 129.

[2] Schimper, "Ueber die Krystallisation der eiweissartigen Substanzen." Zeitschr. f. Kryst., v., p. 132 and p. 160. Comp. *Ibid.*, p. 157.

[3] *Ibid.*, p. 133.   [4] *Ibid.*, p. 135.

[5] *Ibid.*, p. 133.   [6] *Ibid.*, p. 150.

[7] *Ibid.*, p. 151.

tion, their faces becoming crooked or approximating to the spherical.[1]

To compare with the conclusion reached above that the re-introduction of abstracted portions of an intercalated assemblage may restore internal regularity and anisotropism, if the latter subsisted; we have the fact that in some cases imbibition appears to increase the regularity of the internal arrangement of the parts of a crystalloid. Thus when crystalloids of musa or sparganium swell up in pure water the double-refraction materially increases. In the case of the former the phenomenon is very striking, for placed between crossed nicols when dry, or with oil, the light transmitted is very faint, but when so placed after imbibition it shows a brilliant white; and if a quartz plate is used which gives red, we get instead of the slight change of tint produced by the crystalloid before imbibition, vivid yellow, white, blue-green, or green according to the position.[2]

The permeability of the sponge-like framework by a given set of constituents will, according to the above, depend principally on whether their entry will increase the closeness of packing, and in this connection may be mentioned the experimental observation of Tammann that what determines whether or not the respective molecules of a number of liquids shall penetrate a given membrane *is not their relative size*, as has been supposed by Traube and by Ostwald.[3]

We have said that when the framework is squeezed together the maximum distortion of parts will take place near the outer boundaries, because the conditions are there least symmetrical. From the same cause some parts of the shrunken framework will be more prepared to pack closely with the incoming liquid than will other parts, the distribution of this difference being dependent on the outer form of the mass of the framework.

To compare with this we have the fact that if crystalloids of musa hillëi are treated with weak acid, so that a minimum

---

[1] *Ibid.*, p. 153. [2] *Ibid.*, p. 154.

[3] Tammann, "Ueber die Permeabilität von Niederschlagsmembranen." Nachricht der Göttinger Gesellschaft der Wiss., 1891, p. 213. Comp. Walden, "Ueber Diffusionserscheinungen von Niederschlagsmembranen." Zeitschr. f. physical. Chemie, 1892. Bd. x., p. 699.

of imbibition is attained, they display while swelling a remarkable quite symmetrical star-shaped form. This is, however, of short duration, the faces of the crystalloids being quite plane when the process is completed.[1]

If the process of formation of intercalated solid and liquid assemblages, just described, is not sufficiently uniform and gradual for the combination produced to display uniformity of orientation throughout any considerable space, shrinkage and imbibition may nevertheless take place, much as in the cases above referred to, and we may have mixtures or intercalations of practically amorphous assemblages possessing the qualities referred to above.

And as resembling these less regular mixtures, the gelatinous bodies known as colloids may be instanced.

Increase of disturbance and the strain occasioned by the intussusception of portions of a liquid assemblage may, it is conceivable, rupture a sponge-like framework of the kind referred to and reduce it to fragments, which, although no longer able to impart to the mass the properties of a solid, may have considerable magnitude as compared with the distances apart of the ultimate constituents, and may hinder very materially the relative movement of its parts.

To compare with this we have the interesting fact that colloids will not diffuse in colloids.

A further reference to crystalloids is made presently in connection with a certain kind of diffusion.[2]

Intercalation or intermingling of two fluid assemblages. Comparison to solutions.

When two assemblages which pack closer when apart, and are at the same time so related that layers in one are more or less compatible with layers in the other,[3] *do not either of them solidify when they come in contact,* there will, nevertheless, as in the cases above dealt with, be some amount of intercalation or intermingling as a consequence of local disturbances.[4]   And indeed *if these*

---

[1] Schimper, " Ueber die Krystallisation," &c.   Zeitschr. f. Kryst., v., p. 154.
[2] See p. 682.   [3] Comp. p. 649.   [4] See Appendix, p. 687.

disturbances be sufficiently considerable, intercalation will, it is evident, take place even where there is very little or no compatibility between the assemblages coming together.[1]

The mixture will in the latter case be such as is obtained by shaking together different ingredients whose forms are incompatible ; there will be more or less uniformity of distribution but no symmetry, and in no such case can there be absolute homogeneity.

Since the packing is closer when the two kinds of assemblage do not intermix, the principle of closest-packing will, in the cases supposed, be continually to some extent undoing what intermixture the disturbances have accomplished, and producing here and there small patches of each kind unmixed with the other, which patches will however speedily be shaken to pieces again while fresh ones are formed.

The amount of fluctuation going on will prevent any appreciable uniformity of orientation of the patches being exhibited, but it is easy to see that some of the features displayed will be very like those above traced in cases of mixtures which solidify.[2]

Unless *some separating influence is at work*, intermixture of this kind will tend to produce uniformity of distribution of the patches of one kind of assemblage throughout patches of the other; in other words intermixture in all proportions. Separating influences are, however, conceivable, which will remove portions of one or the other kind of assemblage when a certain relative proportion of it is exceeded, *the result being to limit the proportions in which the two assemblages can intermix.*

Thus, for example, in cases where one kind of assemblage would, if found alone, experience a change to the solid state, but is capable of remaining liquid when finely divided and distributed through the other assemblage, it is clear that intermixtures composed of the two kinds in which the predominance of the former is beyond a certain limit will contain patches of the latter large enough to be unaffected by the proximity of the first-mentioned kind. Where this is the case these patches will pass to the solid state, and so the proportion of the kind in excess in the liquid mixture will be reduced till solidification can no longer occur.

---

[1] Comp. Lothar Meyer, '' Grundzüge der theoretischer Chemie,'' p. 128.
[2] See pp. 657–659.

Or, as another example, suppose the two assemblages to be subjected to a uniformly applied force of attraction which affects them differently, so that when the patches of one of them exceed a certain size they have a relative motion with respect to those of the other, which causes them to pass to and assemble themselves at one end of the mixture, leaving only the patches of less magnitude mingled with the other assemblage at the opposite end.

A large class of cases of solution, or diffusion of one liquid in another in variable proportions, may be cited as resembling the sort of intermixture here treated of. For comparison with the case last alluded to, an instance of a pair of liquids commonly spoken of as not intermixing, may be referred to, *e.g.*, water and ether. The two liquids in these cases form two saturated solutions which are moreover in equilibrium together. Thus in the case referred to, we have—1. A saturated aqueous solution of ether ; 2. A saturated etheral solution of water, and both solutions have the same vapour pressure.[1]

Other kinds of diffusion are referred to later.[2]

Let us pass on to the consideration of the fourth class of effects mentioned at the opening of this memoir.

IV.—The interlacing of different kinds of groups or individuals converting a fortuitous assemblage into an assemblage which approximates to homogeneity, but does not reach it because the arrangements for closest-packing are not homogeneous ones.

This effect of the law of closest-packing is, in all probability, precisely that already treated of in dealing with thin curved assemblages ;[3] it is likely that in all cases where the closest-packed arrangement is not a homogeneous one, it will be some such symmetrical departure from homogeneity as that already shown to be productive of curved assemblages.

A mass of similar assemblages of the kind referred to, if the curved fragments be of *small* extent, will be practically

---

[1] As to saturated mutual solvents see Duclaux, Ann. chim. phys. (5) 7,267, 1876. Alexejew Wied. Ann. 28, p. 305, 1886. Comp. "Die Phasenregel" von Dr. W. Meyerhoffer, p. 40 and Lothar Meyer, " Grundzüge &c.," p. 119.

[2] See page 679.   [3] See p. 569.

amorphous, *i. e.*, destitute of any qualities depending on direction, *but at the same time it will present general uniformity of distribution of the constituents*. We shall indeed picture a mass of similar curved assemblages, just like a single continuous assemblage, as continually striving after that relative arrangement of the parts composing it in which it occupies least space, but that owing to inability to reach stable equilibrium it continually fluctuates from one imperfectly symmetrical closest-packed arrangement to another as it is shaken up by passing disturbances. The different constituents will be very evenly distributed and a like relation of parts will frequently be found repeating itself in various places in the mass.

If a collection of very minute assemblages thus circumstanced be solidified we shall look for the production of a practically homogeneous amorphous solid, destitute of any appreciable symmetry, and therefore paralleled by the amorphous or non-crystalline state of bodies.

It should be remembered, however, that we have concluded that some thin curved assemblages are convertible by accretion, under favourable conditions, into homogeneous assemblages,[1] and it is conceivable that this may always or nearly always be the case. With this we may compare Lehmann's conclusion that the amorphous state is due to hindrances which prevent the molecular forces from achieving the degree of symmetry of arrangement which they would otherwise attain.[2]

The next effect to be considered is :—

V.—Combination of two or more homogeneous or approximately homogeneous assemblages to form a single homogeneous or approximately homogeneous assemblage. Resemblance of this effect (*a*) when in its most perfect form, to that highly-symmetrical intermixture of the combining atoms or complexes which must, it is evident, accompany or precede a chemical synthesis; (*b*) when in its less perfect form, *i.e.*, where the assemblage produced is only imperfectly homogeneous or is fluctuating, to some phenomena of diffusion.

If in an assemblage composed of one or more different kinds of

---

[1] See p. 572.

[2] See Lehmann in Zeitschr. f. Kryst. 1, pp. 116, 117, and comp. Pope's translation of Fock's " Chemische Krystallographie," p. 61.

balls, or mutually-repellent particles, the arrangement is the closest-packed possible, and this assemblage is brought in contact with another differently-constituted assemblage which is also in this condition, and *if an intermingling of the assemblages enables the balls, or particles, to pack still closer*, then it is evident that in obedience to the principle of closest-packing, the two assemblages will combine to form a single assemblage.[1]

The process will commence at the boundary where the two assemblages touch, and they will gradually interpenetrate one another.[2]

If closest-packing is reached in a homogeneous arrangement, the resulting compound assemblage will, under sufficiently favourable conditions, be homogeneous, and therefore display one of the thirty-two kinds of symmetry proper to crystals;[3] if not it will be amorphous.

The two assemblages will ultimately combine in the proportions in which they pack closest, and if there is an excess of one of them over the quantity requisite for this combination, the excess will remain uncombined.[4]

Moreover, it is not necessary to suppose that all parts *of any considerable portion*, either of the constituent assemblages before the combination, or of the resultant assemblage afterwards, *reach a condition of equilibrium simultaneously;* the combination will still take place if disturbances are occurring which prevent any great continuity in either time or space of the symmetrical arrangements towards which the principle of closest-packing is continually urging the mass. We may have, instead of very perfect homogeneous assemblages whose continuity is unbroken over a con-

---

[1] The conditions are taken to be uniform throughout the mass. If they are not we may have closest-packing reached in one kind of arrangement at one place, in another kind at another.

[2] This is better understood if we take mutually-repellent particles and not balls. Compare note 1, p. 549.

[3] Zeitschr. f. Kryst., 23, p. 1.

[4] While the mass remains fluid there will be no hard and fast boundary between the combined and uncombined portions thus produced; particles at the edge of the combined portion will continually fall out of combination again, while, to compensate this, particles at the edge of the uncombined portion will become combined; there may also be transitioual combinations. See below, p. 680.

siderable space, a number of similar but not continuous assemblages variously orientated and in a state of fluctuation, but every portion of which now and again becomes very homogeneous indeed, and these fractional assemblages may consist either of unlinked balls (or mutually-repellent particles) or of groups, or partly of each.

And where the arrangement of the constituents is thus fluctuating about an ideally symmetrical one, it is evident that some of the properties of the ideal arrangement will be wanting, while others will be present—those relating to orientation, which depend on extensive continuity of a single homogeneous assemblage, will not be traceable, while those which depend on local symmetry or configuration of the groups apart from orientation, or on mere evenness of distribution, will display themselves.

If no change of state[1] occurs to stereotype the arrangement reached in the homogeneous condition which from time to time recurs in the different parts of the mass, the making and unmaking of this highly symmetrical disposition may go on continually, wherever the materials for it are present, without leaving any permanent trace beyond the achievement, where the conditions are uniform, of a practically uniform intermixture of the different balls, or mutually-repellent particles, or groups, in more or less definite average proportions.

A fluctuating mass, such as is here conceived, will not, however, owing to the many irregularities produced by the disturbances, attain *as a whole* the definite combining proportions found in a tranquil homogeneous assemblage, *but if the particular homogeneous arrangement thus momentarily and locally brought about is one at which a linking together of previously unlinked balls or mutually-repellent particles occurs*, and this change of state does not occur where the regularity falls short of this, the mass may, at least partially, notwithstanding the disturbances, pass by degrees, as here and there the requisite arrangement is produced, into a new *permanent* combination of a definite symmetrical character.

A simple assemblage may undergo a change of state analogous to that here attributed to a compound assemblage. For suppose that a number of grouplets, all of the same kind, are momentarily

---

[1] This investigation does not explain, but merely premises change of state. Compare note 2, p. 687.

or permanently arranged by the action of the principle of closest-packing to form a homogeneous structure, and that the nature of the arrangement produced is such that these grouplets are found placed around axes of revolution of the homogeneous structure, *i. e.*, so that each grouplet is related to the other grouplets ranged with it around the same axis, or point of intersection of intersecting axes, in a different manner from that of its relation to any of the other grouplets. We then see that a linking together or polymerisation of the grouplets to form larger groups may occur wherever the arrangement is sufficiently perfect, and *without destroying homogeneity.*[1]

Permanent combinations brought about in the way above described will differ in character according to the nature of the change of state which occurs. If the fresh linking which takes place is, although symmetrical, not such as to constitute a continuous mass, it will merely produce new groups of one or more different kinds (polymers), which will be thrown into various orientations by the passing disturbances and yet strive again and again to recur to the closest-packed symmetrical disposition of which they are capable.[2] If, on the other hand, the linking is continuous, it will result in the production of a continuous solid homogeneous assemblage capable, under favourable conditions, of symmetrical growth by accretion.[3]

And when a solid assemblage has resulted and afterwards experiences a change of state which liquefies it, *i. e.*, breaks it up into isolated units, its properties thus brought to light will depend on the way in which the links break—we may have sufficient links surviving to connect all the particles contained in a unit of the mass so that but one kind of group is produced,[4] or we may have some of the links which bind the various parts of a unit together too weak to survive the passage out of the solid state, in which case two or more different kinds will be produced.[5]

Again, a combination different from those just described is conceivable *in which one of the combining constituents consists of a solid assemblage* i. e., *of one in which the linking of the parts prevents any permanent alteration of their relative situations.*

---

[1] Compare p. 585.   [2] Compare p. 584.   [3] Compare p. 565.
[4] See p. 584. Compare Min. Mag., vol. xi., p. 130.   [5] Compare p. 619.

In this case the other constituent will consist of balls sufficiently small to be inoperative in the sense above defined,[1] or at least so small as not to be prevented from entering the interstices of the solid constituent.

Finally, in a combination of two *fluid* assemblages there are two ways in which the balls or groups forming one constituent can be conceived to be related to those of the other, and this is the case whether the intermixture is accompanied by change of state or not. Either the balls of both constituents may be operative or those of one constituent may be all inoperative. And a complete gradation is conceivable from extreme cases of the first kind, in which each constituent is equally concerned in determining the kind of arrangement to be displayed by the compound assemblage, to cases in which nearly or quite all the general arrangement is done by the balls of one constituent only, the other, in obedience to the principle of closest-packing, just filtering into the available interspaces without producing any material permanent effect on the arrangement of the balls among which it intrudes itself.

The rate at which intermixture proceeds will, it is evident, largely depend on the nature of the relation just referred to.

Local disturbances, whether brought about by external causes— as stirring or shaking—or by changes occurring within the assemblages themselves, or arising partly from both sources, will, it is evident, on the one hand, promote intermixture and render its progress more rapid, but on the other hand, they will, if they continue, hinder the intermixture from becoming completely symmetrical or homogeneous. Disturbance followed by a gradual passage to tranquillity will best promote the formation of a homogeneous intermixture by the action of the principle of closest-packing.

Deferring the consideration of one or two details of the intermixing of assemblages for a moment, let us now compare the processes thus traced with actual phenomena.

We have just seen that in the presence of the disturbances referred to, *permanent* combination *in precise proportions* will only occur where the local attainment of perfect homogeneity brought

---

[1] See p. 547. This is more readily understood if we take mutually-repellent particles instead of balls.

about by the principle of closest-packing is immediately productive of a change to the linked condition not produced by any less close and symmetrical juxtaposition. Now, in order that the new molecules formed when a *chemical synthesis* takes place may all have the like composition, it is manifest that the atoms which combine to form them must, as an antecedent condition, by some means or other come to be distributed through space in the precise proportions obtaining in these molecules. Consequently this uniform intermixture of the combining atoms or complexes which accompanies or precedes the act of chemical synthesis may be instanced as greatly resembling the combination in precise proportions of two fluid assemblages which paves the way for a change of state as described above.[1]

This change of state, which stereotypes the homogeneous arrangement reached by the assemblage, has its representative in the chemical change or act of synthesis whose occurrence is evidenced by change of properties and manifestation of energy.

The intermixture which accompanies or precedes the production of definite compounds containing *water of crystallization,* or of those double salts whose constituent salts are held together so loosely that the tie does not survive the passage to the liquid state, also furnishes a resemblance to the symmetrical intermixture leading to change of state above referred to; the only difference is that in the fluctuating or liquid state there will be at least two kinds of separate groups present in a compound assemblage which is paralleled by the last-named cases, and not one kind of group only.[2]

The change known as polymerisation resembles the symmetrical compounding of groups occurring in a simple assemblage in the way above described, *e. g.,*
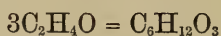
$$3C_2H_4O = C_6H_{12}O_3$$
3 mols. acetaldehyde = 1 mol. paracetaldehyde.

When the homogeneity produced locally is not stereotyped as it arises by a contemporaneous change of state, and thus the

---

[1] See note 1, p. 675.

[2] Comp. Pope's translation of Fock's " Chemische Krystallographie," pp. 36, 37, &c.

passing disturbances continually cause lapses to irregularity, the effects which must evidently be produced find a very close parallel in certain phenomena of *diffusion* where there are limits to the combining proportions. For in the case of the hypothetical combination, as in that of diffusion, we shall have intimate intermixture in practically uniform proportions throughout, without any definite orientation, and a saturation-point whose position will practically be definite, and depend on the amount of disturbance prevalent,[1] as well as on the nature of the ideal equilibrium arrangement.

The rate at which intermixture takes place will, as has been said, largely depend on whether operative[2] constituents are to be found in both combining assemblages or not, and on the part the latter respectively take in determining the nature of the ideal equilibrium arrangement.

We can conceive of assemblages composed of linked groups whose forms are such that the different groups fit together so ill that the law of closest-packing affords great resistance to intermixture in any proportions regular or otherwise. And this is paralleled by some of the cases in which liquid bodies will not diffuse into one another.[3]

Comparisons may be instituted with the diffusion of gases as well as with the diffusion of liquids.

There are also resemblances to the case of a solid assemblage receiving within its interstices inactive constituents in obedience to the law of closest-packing. Thus we have the common phenomenon of solid bodies taking up small quantities of water or certain other liquids, without material change of properties; in some cases the liquid previous to its absorption being gaseous, as in the case of hydrogen occluded by platinum or palladium.

In cases of the latter kind the comparison is instituted with the subsequent intermixture, and not with the change of state.

Having thus indicated the general resemblances subsisting between actual phenomena of combination and intermixture and the behaviour of our hypothetical assemblages, a few additional

---

[1] In the case of diffusion, the vigour of local disturbances is probably traceable to temperature conditions. (But see Appendix, note 1, p. 688.)

[2] See p. 547.   [3] Comp. pp. 670 and 672.

details of the action of these assemblages when combining may be given, and a few further resemblances pointed out before quitting this part of the subject.

It has been stated above that two assemblages will ultimately combine in the proportions in which they pack closest; this refers to the *completed* process, there may, and indeed generally will be transitional combinations, some of them homogeneous, and which, as compared with the constituent assemblages unmixed, produce increased closeness of packing, but not the closest possible.

Suppose, for example, to take a very simple case, that a set of unlinked balls A, mixed with a set of unlinked balls B, pack closest when they are homogeneously arranged in a certain way which employs the two kinds in the numerical proportions 1 : 2. It is then evident that other homogeneous arrangements of the balls are possible into which they enter in equal proportions, and that one of these may, while it does not give such close-packing as that of the arrangement just referred to, give closer-packing than is attained by the balls when unmixed. Also that during the process of intermixing to produce the closest-packed arrangement, the balls may here and there fall into this less closely-packed arrangement.[1] And although if its attainment anywhere is not accompanied by a change of state which stereotypes it, such an arrangement will prove but a temporary one, *it will be made permanent if a change of state fixes it as it is here and there produced.*

Any hindrance to the achievement of the closest-packing possible, such, for example, as a scanty but widely disseminated supply of some of the materials, will be likely to favour the production of this less closely-packed combination.[2]

The closest-packed arrangement will be appropriately called *saturated*, and transitional combinations *unsaturated*,[3] the properties expressed by these terms being closely paralleled by the properties of chemical atoms thus named, both in cases of chemical synthesis, and also in those of diffusion.

---

[1] This is somewhat analogous to the accidental twinning above referred to.   See p. 620.

[2] The method of production of a second combination from the same constituents which is here described must not be confounded with that based on change of conditions. (Comp. pp. 575 and 678.)   [3] Comp. p. 607.

The attempt made to formulate a general law respecting the combining properties of different chemical atoms which shall assign to each kind its definite value, or "*valency*," with respect to other kinds has, it is well known, met with but very limited success, and it cannot therefore be regarded as surprising that among the geometrical properties here traced no general law of valency of the various kinds of balls finds a place. It is true that in any given combination each kind of the hypothetic balls can, when the conditions are given, be seen to have its own proper combining proportion, but it is not easy to see how the proportion observed by a given kind in one combination will be related to the proportion observed by the same kind in another different combination.

It is interesting to notice that increase of disturbance will diminish the efficiency of the principle of closest-packing, *i.e.*, will hinder it in availing itself of the compatibility of units for fitting close together when appropriately intermixed; and that resembling this we have the fact that increase of temperature diminishes the number of chemical bonds of substances capable of combination, and weakens their exhibitions of affinity, so that above a certain limit of temperature there is no strictly chemical action. Further, that change of temperature in the other direction greatly complicates the chemical effects.[1]

In this connection we may call to mind the fact that the stability of some of the carbon compounds which produce rotation of the plane of polarization is destroyed by a moderate rise of temperature.[2]

Where the interpenetration of two assemblages depends on the closeness of packing being increased by the intermixture, it is evident that portions of a third assemblage present in one of the two assemblages which intermix may occupy some of the interstices and hinder the process; it may also disturb the symmetry, and in this way prove a hindrance.

In connection with this may be cited the observation of Arrhenius, that the presence of a percentage of alcohol in

---

[1] Compare Bischoff's "Handbuch der Stereochemie," p. 42.

[2] *Ibid.*, p. 87.

water considerably lowers the rate of diffusion of a diffusing body.[1]

The action of the principle of closest-packing may cause an assemblage which consists of, or contains a linked framework[2] to exhibit a selective action on assemblages brought in contact with it. Thus for closest-packing to obtain, a certain set of balls may have to occupy the interstices among the balls of such a framework, and to quit the interstices of another assemblage in contact with but outside it.

In this connection we may recall the phenomenon of the removal of dye-stuffs by the action of crystalloids. Fuchsine blue, in particular, is greedily taken up by many crystalloids, so that in twelve hours a brightly-coloured solution of this substance may be rendered entirely colourless by the action of these bodies lying in it.[3]

We come now to :—

VI.—**The breaking up of an assemblage into two or more distinct assemblages ; an effect which resembles the disentangling of the separating atoms or complexes that commonly follows a " chemical decomposition," and also resembles the crystallizing out of a constituent from a liquid or partially liquid mixture.**

If an assemblage composed of two or more different kinds of units, whose arrangement at the time of its formation was the closest-packed possible, *is subjected to a change of conditions such that this arrangement ceases to be so*, it is evident that, if the state of the assemblage as to linking permits, it will in obedience to the fundamental law of closest-packing break up into two or more assemblages of different kinds.

The re-arrangement of the parts to form these separate assemblages will be such as to give closest-packing under the new conditions, and these assemblages will be homogeneous or amorphous at the behest of the principle of closest-packing.

---

[1] "Untersuchungen über Diffusion von in Wasser gelösten Stoffen." Zeitschr. f. physikal. Chemie, 1892, Bd. x., p. 51.   [2] See p. 666.

[3] Schimper, " Ueber die Krystallisation der eiweissartigen Substanzen." Zeitschr. f. Kryst., 5, p. 156.

As in the case of assemblages combining, it is not necessary to suppose that all the parts of any considerable portion of the changing mass reach a condition of equilibrium simultaneously ; the effect will still take place if the passing disturbances are such as to prevent any great continuity in either time or space of the new symmetrical arrangements produced. And as was just now pointed out, if any particular homogeneous arrangement momentarily and locally brought about is one at which linking occurs, and this change of state does not occur where the regularity falls short of this, the mass may at least partially, notwithstanding the disturbances, pass by degrees, as here and there the requisite arrangements are produced, into new permanent combinations, of definite symmetry.[1]

We find a resemblance to the process just described in the orderly separation of different kinds of atoms which follows a chemical decomposition, the mass breaking up into less complex substances of a definite composition.

Also, in the orderly arrangement arrived at by the atoms of a body as it crystallizes out of a liquid or semi-liquid mixture.

VII. —The exchange of some of the constituents of two or more assemblages so as to constitute fresh assemblages; an effect which resembles the redistribution of the atoms which occurs in a chemical double decomposition.

If two assemblages, each of which is composed of one or more different kinds of balls, whose arrangement is the closest-packed possible, are when brought together capable of closer-packing if a redistribution of the balls is made by which two fresh assemblages are formed, it is evident that, unless the linking in the original assemblages prevents, the action of the principle of closest-packing will produce such a redistribution.

In some cases the effect may be produced by a combination of all the constituents to form a single assemblage, followed by a separation along fresh lines, while in other cases an actual interchange takes place at all points where the parts in juxtaposition have not the closest-packed arrangement possible for them ; one

---

[1] Comp. p. 674.

kind filtering in one direction, another in the opposite direction at the same time, and the process continuing until the arrangement throughout is of the closest-packed nature. If the constituents dislodged are, before the change occurs, linked to other parts of the same assemblage, the readiness with which the links break will do something towards determining which of these two alternatives prevails in any given case.

As before, it is not obligatory to suppose the newly-formed assemblage to be continuous ; it may be produced in comparatively minute fragments as here and there the requisite symmetry is from time to time reached, and then stereotyped by the formation of links.

The readiness of a compound assemblage to effect exchanges of this kind with other assemblages will depend on whether its constituents are loosely or closely packed, in other words on the extent to which some constituent of it is *saturated* with the others.[1]

This corresponds very well with the facts concerning double decomposition. Thus in speaking of certain cyclic compounds, Bischoff says, that the *dimethylene* complex is very unstable and is broken by hydrogen bromide, bromine, and even by iodine. *Trimethylene* is alone decomposed by hydrogen bromide, not by bromine. Finally *tetramethylene* and *hexamethylene* are very difficult to break or not to be broken up.[2]

Inversion by exchange.

Suppose that a certain collection of balls is so constituted as to find equilibrium in two slightly different homogeneous assemblages under some slight variation of the conditions, and that when these assemblages break up into groups as a change to the partially-linked or liquid condition[3] takes place, these groups are in both cases all of one kind and the composition the same in both cases ; *and suppose further that the two assemblages of groups A and B are so related that the only material difference in the arrangement, apart from the linking, is that one kind of ball in A occupies entirely different situations from those it occupies in B, and that the unoccupied points in B, which correspond to the places of these balls in A, and also the unoccupied points in A, corresponding to the places of the same balls in*

[1] See p. 680.   [2] Bischoff's "Handbuch der Stereochemie," p. 51.   [3] Comp. p. 583.

B, are places of most open or loosest packing, then it is evident that the following reciprocal relation between the two assemblages may be looked for:—

When two parallel exchanges of the kind above referred to are effected between a third assemblage and the two kindred assemblages respectively, the balls newly arriving in *A* are likely to fill the blanks whose positions correspond to points already occupied in *B*, and the same balls newly arriving in *B* are likely to fill the other kind of blanks corresponding to points already occupied in *A*, and if in the assemblages formed the influence of the newly-arrived balls predominates, the result will be that the new assemblage formed from *A* will resemble *B*, while that formed from *B* will resemble *A*. And this will be the case whether or no the original balls whose positions were different break away and are expelled by the action of the principle of closest-packing, *i. e.*, whether the re-arrangement is of the nature of a metathesis or a synthesis.

It is perhaps interesting to notice that if the positions of the balls thus exchanged are singular points they will, when occupied, probably be the centres of the respective groups, and as a consequence, the parts of the assemblages turned towards the centres of the groups in the one will be found turned towards the outer boundaries of the groups in the other related assemblage.

A resemblance to the effect above described is found in the behaviour of the isomeric acids, *fumaric acid,* and *maleic acid,* the former combining with bromine to produce bromo-maleic acid, and not a derivative of fumaric acid—and the latter, in conjunction with the same element, forming bromo-fumaric acid.

It is easy to see that if two assemblages are related in the way just described and intermixture of either of them with some third assemblage effects the transformation to the form of the other, this intermixture need not necessarily be followed by a linking in of the new constituent, as in the case just treated of, *and if there is no such linking in, a very small quantity of the third assemblage may, by travelling about effect the transformation of a large quantity of whichever of the two assemblages is less stable into the more stable form*; there will also be the converse transformation, but naturally the one named will predominate.

Resembling this we have the fact that mere contact with some

substances effects the spontaneous transformation of certain ethylene compounds into their isomerides. Thus the presence of traces of iodine causes the quantitative transformation of ethylic maleate into ethylic fumarate.[1]

———

APPENDIX.

The main ideas which form the basis of the foregoing inquiry viz. closest-packing, mutual repulsion of particles, ties or restraints on this mutual repulsion, are all old conceptions—they have been used by earlier writers and are still adopted by living scientists.[2] Nevertheless it seems desirable to put them collectively, as employed in the present case, into the shape of definite concepts clothed in precise language.

The following is an attempt to do this, but the writer wishes it to be understood that the list of postulates here given is intended as a minimum one—that it is *not to be regarded as complete for any purpose except the production of the effects under consideration*, and that it is put forward *merely as a proposal*, for the purpose of eliciting the criticisms and suggestions of those who, in explaining or elucidating phenomena, have adopted the same or similar concepts.

Proposed Concepts.

1. Particles or centres of influence which are mutually repellent.

2. Each particle to be destitute of polarity so that its influence on surrounding particles is not affected by turning it about its centre.

3. Different kinds of particles to experience different degrees of repulsion from the same particle at the same distance.

4. The mutual repulsion which any two of the particles exercise to diminish as the distance between them increases, and to be always some inverse function of this distance such that when the

---

[1] Hantzsch, *loc. cit.*, p. 83.

[2] Comp. "Molecular Constitution of Matter," by Sir William Thomson, in "Proceedings of the Royal Society of Edinburgh," vol. xvi. p. 693; as to closest-packing, see p. 712; as to mutual repulsion of particles of more than one kind, see pp. 699–700; as to constraints, see p. 699.

distance separating them increases beyond a certain limit the mutual repulsion falls very rapidly either to zero or to a comparatively low value. The position of this limit to depend on the nature of the particles and the conditions affecting them at the moment.

5. A general force of compression[1] to be applied to every assemblage of particles so as to limit the space allotted to it.

6. Every assemblage of particles to be capable of passing into a state in which movement of some or all of the particles with respect to one another is so restricted as to be almost negligible; in other words, into such a state as would be produced by connecting some or all of the particles closely contiguous to one another by very slightly elastic strings drawn straight, similar lengths being employed to connect similar pairs of particles. And such a change of state may or may not be accompanied by a change in the mutual repulsions exercised by the repellent particles; and the latter change, if there be one, may consist in an increase or a decrease of these repulsions.

And every assemblage thus changed to be capable of passing partially or entirely out of this state of restricted movement back to the condition in which the movement is unfettered.[2] And the connection established between the particles is to be regarded strictly as a property of their conditions, and as enduring only so long as the conditions capable of producing it endure, so that a fluctuation of the conditions might produce alternate tying and untying of the links connecting the particles of an assemblage.

7. All assemblages of particles are supposed to be continually exposed to small (inconsiderable) local passing disturbances adequate to displace any equilibrium which is not the most stable

---

[1] Any other restraint or attraction which, while preventing indefinite expansion, permits the interaction of the mutual repulsions, will do equally well. Compare Boscovich, "Theoria Philosophiæ Naturalis redacta ad unicam legem virium in natura existentium." Where *all* space is occupied by particles sufficiently near together to repel one another, no restraining force besides inertia may be necessary.

[2] This investigation does not throw any light on the causes or nature of *change of state*, or the causes of *change of volume* of matter, but merely premises that such changes of the assemblages of particles as are here defined can be brought about, and traces some of the effects consequent on these changes.

possible, and, as it were, to shake the particles into new situations, and in this way facilitate their taking up relative mean positions which give stable equilibrium.[1] The linking premised in No. 6 will, however, where it is present, limit or prevent this effect.

8. In some cases these disturbances are increased so as to produce a retrograde condition and disturb existing equilibrium.

It is evident that in all cases whatever, in which stable equilibrium is attainable, the arrangement of particles whose nature has been thus premised will, if we neglect the small disturbances, ultimately come to be such that the pressures subsisting between them, together with the external force of compression, form a system in stable equilibrium.[2] And as, according to one of the data just given, the mutual repulsions fall off rapidly when the distance separating two particles passes a certain limit, this statical equilibrium may be regarded as that of the stronger repulsions, *i.e.*, of those between particles whose distances apart are within these limits, the weaker repulsions, if any, subsisting between the particles whose distance apart exceeds these limits being negligible.

Thus all repulsions between the particles, except those between each particle and the particles closely surrounding it, are to be taken as negligible.

Fundamental Law of Closest-packing.

Whether the particles are all of one kind, or of two or more different kinds, the effect of the mutual repulsions, under the conditions stated, exclusive of No. 8 above, will be to continually

---

[1] The small movements of the particles may be oscillatory; indeed the interaction of the repulsions will, if the particles have inertia, cause them to be so, but it is not necessary for our present purpose to attribute any persistence or regular periodicity to any of the oscillations, although the existence of some kind of regularity is not precluded.

The origin of the disturbances is immaterial; one thing is however clear: the interaction of the hypothetic particles will, if they have inertia, cause a disturbance occurring at any point to be communicated to other points around by wave-movements of some kind.

[2] If the attainment or persistence of complete equilibrium is prevented by the passing disturbances referred to, the given conditions will nevertheless be found continually removing the traces of every slight retrogression thus caused and striving after the equilibrium arrangement.   (Compare p. 674).

modify at every part of an assemblage any subsisting arrangement of the particles in such a way as to produce closer-packing, until an arrangement is reached which gives at every part the closest-packing attainable. For while the most obvious way of describing closest-packing is to say that it consists in getting the greatest possible number of certain bodies into a given space, if, instead of making the *number* we make the *size* variable, we can define it as the packing of the largest sizes of a number of bodies of certain patterns into a given space, *e.g.*, if the balls contained in a bag all swell uniformly the bag will be closest-packed when the maximum enlargement of the balls has taken place. And the effect of the hypothetic repulsions in making the particles get as far from contiguous particles as possible, can be regarded as equivalent to the swelling of spheres described about the latter as centres.

As only the repulsions between *near* particles are operative, each part of the assemblage affects other parts not in immediate proximity to it *only so far as its changes affect the general pressure, or set up travelling waves of fluctuating pressure*; and although no doubt, in most cases, the united effect of the particles everywhere packing as close as they can will be to make the assemblage, as a whole, ultimately occupy the least space possible under a given pressure,[1] this is not necessarily the case always when we are dealing with assemblages the movements of whose particles are gradually becoming restricted in the manner defined.[2]

The effect referred to, which we may call *the law of closest-packing*, may be stated concisely thus.

Every assembly of mutually-repellent particles whatever, which fulfils the above definitions, will continually approximate to, or strive after, that relative arrangement of the particles composing it in which it has come at every part to occupy a minimum space under a given general pressure, or average repulsion between the particles. And this will be true whether the assemblage is capable of ultimate stable equilibrium or not, and even if the disturbances referred to are such as to undo what is accomplished of closer-packing as fast as it is achieved.

[1] See No. 5 in the above list of Data.
[2] Compare conclusions as to bent and branched crystals, p. 568.

INDEX.

LXIII.

ARRANGEMENT OF THE CRYSTALS OF CERTAIN SUBSTANCES ON SOLIDIFICATION. By FRED. T. TROUTON, D.Sc., F.R.S.

In the case of certain substances, an arrangement of the crystals on solidification would appear probable from the following considerations :—

The substances are those whose conductivity for heat varies with the direction the heat is travelling in the crystal.

Suppose a mass of the molten substance beginning to solidify in consequence of heat escaping through its boundary, crystals will begin to form at the boundary. The axes of these incipient crystals may, in the first instance, lie equally in every direction. However, those crystals whose axes of best conductivity lie parallel to the flow of heat will now allow heat to pass out faster than those in any other direction, and, consequently, at these points more rapid solidification will take place than elsewhere.

Now it would appear to be a justifiable assumption to make, that this solidifying matter will, in general, add itself to these particular crystals, or at least take up sensibly the same axial direction through the well recognized tendency of substances, on crystallizing, to follow any example ready to hand. If this be so, those crystals with their best conducting axes normal to the isothermal surfaces, or surfaces across which the heat is flowing, will grow the fastest by a kind of " survival of the fittest " ; and under suitable conditions an arrangement of the crystals may prevail with the axes lying parallel. Such an arrangement of a mass crystallised from fusion is often to be observed on fracture.

Though the relative conductivities, in different directions, of a

great number of crystals have been determined, it so happens that few of these are available for the purpose of testing this question, as most of these substances are not such as readily yield crystals from fusion.[1]

The conductivity of ice has been determined by G. Forbes to be greater in the direction of the hexagonal axis than at right angles to it, in the proportion of 22 to 21. Under favourable conditions even this slight difference would appear to be sufficient to determine the arrangement of ice-crystals, so as to have the best conducting axis parallel to the flow of heat. Mr. M'Connel[2] and others have drawn attention to the curious hexagonal arrangement of vertical crystals to be observed in the ice formed on a sheet of water under particularly calm conditions.

On the other hand, bismuth, which crystallizes in the same system, was found by Jannetaz to have a conductivity less in the hexagonal axis than at right angles, in the ratio of about 2 to 3.

It is not difficult, as is well known, to get crystals of bismuth formed at a surface through which heat is passing out, by allowing a vessel of the molten material to cool down a certain amount, till crystals have formed over the sides of the vessel, and then to pour the rest of the still molten bismuth out. The crystals so obtained are rhombohedrons, and are seen, in the great majority of cases, to point with one corner inwards. The rhombohedron is so nearly a cube that it is only by exact measurement it can be ascertained whether it is the corner at the hexagonal axis (which would not agree with the above supposition), or one of the others which would permit the maximum rate of dissipation of energy.

Several of these crystals were measured with the goniometer, and in each case the corner pointing inwards was that agreeing with our theory.

It is obvious that further observations are most desirable before accepting any conclusion of this character, but this can only be effected on the accumulation of further thermal conductivity data for crystals.

---

[1] The author hopes, when opportunity offers, to make determinations of the relative conductivities of certain crystals, such as, say, sulphur, &c.

[2] *Nature*, vol. xxxix.

LXIV.

PHELLIA SOLLASI: A NEW SPECIES OF ACTINIARIAN FROM OCEANIA. By ALFRED C. HADDON, M.A., D.Sc., Professor of Zoology, Royal College of Science, Dublin.

My friend Dr. W. J. Sollas, F.R.S., Professor of Geology at Oxford, asked me to identify one or two sea-anemones that he had collected in the lagoon at Funafuti, Ellice Group, W. Pacific, in 1896. They all belonged to the same species. Their anatomy has been studied by my friend and former pupil Dr. Katharine Maguire, and from the information she has supplied me I am able to determine the systematic position of this new form.

Phellia Sollasi, n. sp.

Form.—In the preserved specimens the body is fairly cylindrical with an expanded base in some specimens. The surface is thrown into folds of contraction, but no warts, suckers, or other prominences are visible. There is a thin cuticle. The disk is largely covered by the contraction of the upper portion of the column.

Tentacles short, stout, entacmæous, in three or four cycles, from about 48 to 54 in number. They are evidently very contractile, judging from the radiate grooves at their apices.

Colour.—No observations were made as to the colour of the living polyp.

Dimensions.—The height of the preserved specimens varies from about 15 mm. to 23 mm. The average diameter of the column is from 8 to 10 mm.

Habitat.—Coral reef, Funafuti, Ellice group.

This actiniarian belongs to the family Sagartidæ as it possesses numerous and characteristic acontia.

The Sagartidæ have not yet been satisfactorily subdivided, but

as the typical sub-family, the Sagartinæ, have numerous perfect mesenteries which bear gonads, as do also the other well-developed mesenteries, this species cannot be placed among them.   Nor can it be located in Carlgren's sub-family Metridinæ in which the chief mesenteries are sterile.   Both these sub-families possess cinclides.

The Chondractininæ have only six perfect mesenteries, but these are sterile.

The anatomy of only one or two species of Phellia has been studied.   Andres (" Le Attinie," 1884, pp. 73, 74) gives diagrams of the general structure of *Phellia limicola* (Andr.), and quite recently Kwietniewski has described *Phellia ternatana*, n. sp. (Zool. Anzeiger, 1896, No. 512 ; " Actiniaria von Ternate," Abhandl. Senckenbergischen naturf. Gesellsch. xxiii., 1897, p. 321); and he alludes (p. 327) to *P. ambonensis*, and *P. decora* (?), Klunz., from Ambon and the Red Sea respectively.

I have also studied an undescribed species of Phellia from Torres Straits.   In all of these there are only six pairs of perfect mesenteries, and these alone are fertile.   The present species agrees with the above-mentioned five species in this respect, and therefore I have no hesitation in placing it in the genus Phellia.

In the present state of our knowledge, I consider the presence of gonads in the six pairs of primary mesenteries in Phellia, and their absence in the Chondractininæ, to be of sufficient importance to place that genus in a distinct sub-family, for which Verrill's (1886) name, the Phellinæ, may very well be retained.

Kwietniewski considers the Chondractininæ as a synonym of the Phellinæ, which he defines as—" Sagartians with a cuticular covering to body-wall."   For the reasons stated above I do not think this definition is sufficiently explicit.

The PHELLINÆ may thus be defined :—Sagartidæ with usually an elongated column, the capitular portion of which is generally delicate and extensile ; body-wall provided with a cuticle, but without any solid or hollow process, such as tubercles, vesicles, or suckers ; no cinclides.   Tentacles simple, neither very numerous nor very long.   Only six pairs of perfect mesenteries which alone are fertile.   The remaining mesenteries are usually feebly developed.   The retractor muscles are very strongly developed on the primary mesenteries.   Acontia usually feebly developed, and

emitted only through the mouth. Strong mesoglœal sphincter muscle.

The genus Phellia has been defined by Kwietniewski (1896) in much the same terms as that which I have adopted for the sub-family.

I have no personal knowledge of the genus Octophellia, Andres (1884), nor can I at present recognise any other genus that belongs to this sub-family.

Phellia Sollasi is apparently closely allied to *P. ternatana*, Kwietn., but differs from it, so far as the preserved specimens are concerned, in having fewer tentacles, more acontia, and no definite mesoglœal muscle in the oral disk.

Reduced ½.

Reduced ½.

LXV.

THE APPARENT COMETARY NATURE OF THE SPIRAL NEBULA IN CANES VENATICI. By W. E. WILSON, F.R.S. (Plate XXI.)

This extraordinary Nebula was discovered by Messier in 1772. He described it as a faint double Nebula whose centres are 4′ 35″ apart, but with its borders in contact. Sir John Herschel observed it ; but the late Earl of Rosse, using his 6-feet reflector, was the first to draw its wonderful spirals. The photograph, which is here reproduced, was taken taken in February, 1897, with my reflector of 2 feet aperture and 10 feet 6 inches focus. The plate used was Cadett's "Lightning" brand, and the exposure was carried on for 90 minutes. If the photograph is carefully examined, it will be seen that, in many places, the nebulous matter is condensing into knots on the great spirals; and what is most remarkable is that these knots are nearly all provided with cometary tails. La Place, in his famous Nebular Hypothesis, assumes that the stars have been formed from masses of nebulous matter which gradually condenses by the action of gravity, and in the lapse of ages forms a central sun.

From the curves of these spiral nebulæ, is it not more probable that we here have repulsive forces at work, and not a streaming in of matter under the action of gravity ?

These spiral nebulæ seem to be a distinct class in themselves. In all the other types of nebulæ, such as the " Dumbbell," the " Crab," the " Ring " nebulæ in Lyra, and many others, we can see no evidence of the forces which are at work in the spirals.

I think the fact that we see these supposed tails where the nebulous matter is condensing into knots on the spirals, is a strong point in favour of repulsive action. It is difficult to see how, even supposing the main spirals to be due to a vortex motion, these secondary tails could be due to anything but a repulsive force.

LXVI.

A THEORY OF SUN-SPOTS.   By J. JOLY, M.A., Sc.D., F.R.S.,
Hon. Sec. R.D.S., Professor of Geology and Mineralogy in the
University of Dublin.

THE temperature of the Solar Photosphere has been variously
estimated.   The recent estimate of Messrs. Wilson and Gray[1]
affords 8000° C. as about the probable temperature.

If this temperature is above the critical temperature of the
mixture of elements present in the hotter parts of the photosphere,
we are led to consider the great mass of the Sun as gaseous ; for it
is very certain that the temperature beneath the photosphere is
still higher.   In fact the actual seat of the evolution of heat must,
on the hypothesis of the dynamical origin of solar heat, be in the
denser body of the Sun lying within the photosphere.

Although the gaseous constitution of the Sun must on this
assumption be admitted as a matter of definition (and the low mean
density suggests that the effect of temperature is to maintain his
exterior layers for great depths in a true gaseous state) the interior
parts of the Sun are at pressures so enormous that the density
probably rises to that of the solid state, and the matter within
assumes or approximates to the physical properties of solid matter.
It would further appear that a true surface cannot be ascribed to
the Sun.   The highly compressed gaseous matter within gives place
to rarer matter as the photosphere is approached, till the density has
diminished so much as to permit of enormous convection currents,
and finally of the great explosive out-rushes observed extending
from the photosphere.   Nowhere would a true surface exist, any-
more than in the experimental tube containing carbon dioxide at a
temperature above 31° C.

---

[1] Phil. Trans. A., vol. 185, 1894.

What the conditions regarding the convective transfer of heat in the deeper layers are we do not with certainty know. The general tendency of pressure to confer solidity may, however, with probability be supposed to confer even at solar temperatures a certain degree of viscosity. In any case, the increased density means increased inertia per unit volume, and therefore involves a less disturbed state of things than is manifest upon the surface.

The intense radiation of the Sun is, on these views, mainly the radiation of matter above the critical temperature. His continuous spectrum is derived from this radiation. Sir Norman Lockyer has shown that such a continuous spectrum is quite in harmony with a gaseous state.

Proceeding outwards in the photosphere a fall in temperature must be supposed to occur. Convective carriage of heat cannot avert this, for any such rise of gaseous matter must be accompanied by dynamical cooling. Finally, a temperature will be reached at which the critical temperature of the mixed elemental gases of that region, or of some one predominant constituent element, say carbon, is attained. When this is reached in a region where the pressure is at, or above, the critical pressure, a rain of matter in the liquid state will occur; such a rain as Amagat observed in his tube of carbon dioxide near the critical temperature of the gas.

That the estimated photospheric temperature of 8000° C. may approximate to the critical temperatures of many of the elements is not improbable when it is considered how high in the scale of temperature even the melting points of many of the metallic elements stand. The melting point of carbon is unknown, and, as appears from the experiments of Mr. Wilson and Professor Fitz-Gerald, is probably above that of the electric arc : 3300–3500° C.

On these considerations a theory of Sun-Spots is suggested. The Sun-Spot is, in fact, a flood or layer of liquefied matter floating upon the denser gaseous matter beneath. It constitutes the first approach to a change of state in the Sun visible to us. At the level of the spot a cooling has been temporarily produced ; possibly due to radiation through parted photospheric gases (and the Sun-Spot is often preceded by more intense local brightness), possibly by sudden expansion attending up-rush from within, the final result being a fall in temperature sufficient to permit

of the formation of a vast area of liquid matter. It is to be expected that the depth in or beneath the photosphere at which this phenomenon will occur will vary, according to the circumstances of cooling. There is every evidence to show that matter thus separated out into the liquid state, and exhibiting the phenomenon of surface tension and a true liquid surface, will differ but little in density from the surrounding gas from which it is derived. Nor is there any physical difficulty in supposing the precipitated liquid to float upon denser gas beneath.

The formation of even large spots is sometimes a matter of a score of hours only, and their disappearance is often as sudden: facts consistent with a simultaneous change of state over a large area.

They are less luminous than the surrounding photosphere. If the liquid matter were opaque—a character we may ascribe with safety to liquid carbon, to the liquefied metallic elements, or to mixtures of these—a great reduction in emissivity would certainly result.

Violently agitated, probably, this ocean would reflect near its margin the surrounding banks of photospheric matter, and, furthermore, the inrush over the cooler area of liquid would tear down these gaseous and cloudy masses on to the surface of the ocean, phenomena producing the intermediate brightness as well as the jagged and often cyclonic appearance of the penumbra. The facts that the limits of penumbra and umbra often follow with rude parallelism the meeting of penumbra and photosphere is consistent with this explanation.

The presence of in-falling cooler gas, as determined by the spectroscope, into the Sun-Spot would similarly follow as a consequence of the fall of temperature over the surface of these solar oceans.

The duration of the spot will depend on the rate at which heat is transferred from beneath into the liquid, as well as upon the rate at which the liquid is fed from above by in-falling rain. In considering the rate at which heat will be transferred into the liquid, it must be remembered that the liquid is under physical conditions resembling those which preserve the drop of water on the red-hot silver plate, in fact is in the spheroidal state. And, again, the rate

of transfer of heat will depend on how nearly the region beneath and around the spot approximates to the temperature of the liquid.

On these views we may infer that the present temporary nature of such developments of liquid matter upon the surface of the sun will in the future gradually disappear. In the present stage of cooling, the diminution of temperature due to loss by radiation over the Solar Spot soon leads to equalisation from within : to a rise in the isothermals and re-evaporation of the liquid. But this will not be so in the remote future. Gradually the internal supplies will diminish and the rate of equalisation will decrease. Spots will be of larger extent and of longer duration, till ultimately the present (probable) state of the Earth is attained, a liquid or viscous mass coated with a solid crust, and agitated with gradually declining volcanic outbreaks. The duration of solar energy as a sustainer of life upon the Earth will probably be limited by the advance of the change of state. When the emissivity of the Sun is thus reduced, his rate of shrinkage and consequent dynamical evolution of heat will correspondingly diminish ; and while his final cooling will be the longer postponed, his radiated energy will be no longer available as a source of life upon his satellites.

It is perhaps not improbable that many irregularly variable stars are in a stage more advanced than the present stage of our Sun. They may constitute in fact an extreme demonstration of the flicker observed in the tube in which matter fluctuates between the liquid and gaseous states. It is not impossible that our problematical Glacial Epoch may be referred to a Sun-Spot period, due to the change of state of some constituent now finally transferred deeper into the gaseous solar envelopes, or to the present gaseous elements condensed and re-evaporated on an exaggerated Sun-Spot period, the cause of which is, however, not assignable.

It is now many years since I heard Dr. G. J. Stoney suggest that a liquid substratum to the photosphere and rents in the latter would explain the appearance of the Sun-Spot. He pointed out that the liquid within would reflect the dark sky, and appear as a less luminous area than the surrounding photosphere. The foregoing speculations obviously involve, in many respects, similar conditions.

LXVII.

OF ATMOSPHERES UPON PLANETS AND SATELLITES.
By G. JOHNSTONE STONEY, M.A., D.Sc., F.R.S.

[ABSTRACT.]

IN a Paper " On the Physical Constitution of the Sun and Stars," in No. 105 (1868) of the Proceedings of the Royal Society, Dr. Johnstone Stoney applied the Kinetic Theory of Gas to the interpretation of some of the phenomena of atmospheres. In it he explained the conditions which, under that theory, limit the height to which an atmosphere will range, and showed that the lighter constituents of an atmosphere will overlap the others. He subsequently extended the investigation in a series of communications to the Royal Dublin Society, of which the earliest was in 1870; and he has given an account of these extensions in the Memoir of which this is an abstract—see Scientific Transactions of the Royal Dublin Society, vol. vi., p. 305, " Of Atmospheres upon Planets and Satellites."

Dr. Stoney explains the absence of hydrogen and helium from the Earth's atmosphere, and the absence of all known constituents of an atmosphere from the Moon, by showing that, in accordance with the Kinetic Theory, these gases are so circumstanced upon the Earth and Moon that the velocities which their molecules can occasionally reach, suffice to enable the gas gradually to drift away; and he further arrives at the conclusion that the same theory implies that the vapour of water cannot be a constituent of the atmospheres of either Mercury or Mars.

The conditions which prevail upon Mars are specially discussed. Since water cannot be present, nitrogen, argon, and carbon dioxide are suggested as the most probable constituents of its atmosphere. Of these the most condensible is carbon dioxide, and to it are referred the snow-caps which are formed alternately on the north

and south poles of Mars. Carbon dioxide would be the heaviest constituent of such an atmosphere, and would in that respect differ from water, which is the lightest constituent of the atmosphere of the Earth. It is inferred from this, that the vapour upon Mars cannot produce elevated clouds floating above the solid surface of the planet, as water does in the Earth's atmosphere, but only low-lying fogs with frosts and snow; and to these, in connexion with the distillation of the vapour alternately towards the two poles, are referred the varying but frequently recurring appearances which observers have recorded upon that planet.

The investigation also offers an explanation of such a gap in the series of chemical elements as we find upon the Earth between hydrogen and helium, and between helium and lithium; and it shows that, if the suspected intermediate elements exist, the conditions upon Jupiter are such that they may all be present in his atmosphere, and that some of them may be present upon the three other giant planets of the solar system, though not upon any of the group of four smaller inner planets to which the Earth belongs.

By an application of the same method of investigation to the satellites and the minor planets of the solar system, the author infers that there can be no atmosphere upon any of these bodies, except perhaps upon the great satellite of Neptune; and with reference to the Sun, it is shown that the greatest size which the Sun can have had since it became a globe—that is, the greatest which is compatible with its atmosphere's having then, as now, contained free hydrogen—is an immense sphere extending from the centre of the Sun out to a situation which lies between where the orbits of Mars and Jupiter now lie; so that from some such immense size as this it may have been since slowly contracting.

Finally, the investigation leads to the conclusion that the molecules of the gases which have from time to time escaped from planets and satellites have but seldom been able to extricate themselves altogether from the solar system; and that the vast majority of them are now circulating in countless numbers round the Sun, like excessively minute independent planets.

LXVIII.

A SPECTROGRAPHIC ANALYSIS OF IRON METEORITES, SIDEROLITES, AND METEORIC STONES. By W. N. HARTLEY, F.R.S., and HUGH RAMAGE, Assoc. R.C.Sc.I., F.I.C.

(PLATES XXII., XXIII., XXIV.)

IN a Paper just published in the Transactions of the Chemical Society, vol. 51, p. 533, on " The Wide Dissemination of some of the Rarer Elements, and the mode of their association in Common Ores and Minerals," we have shown that out of 91 iron ores belonging to the metallurgical collection in the Royal College of Science, 35 contain the extremely rare metal gallium, and most of them contain constituents of an unusual character not hitherto known or suspected to be contained therein. For instance, rubidium appears to be very commonly present, while the mag- netites, from whatever part of the world, invariably contain gallium, but no indium; the siderites all contain indium, but no gallium. We have therefore considered it desirable that meteorites should be examined, and accordingly a selection of specimens was made for the purpose. They are classified into meteoric irons, siderolites, and meteorites, or meteoric stones, and on the following pages their composition is shown, with the collec- tions from which they were obtained.

In the paper mentioned, we have given a list of those elements capable of being detected by our method of examination. Those which are not volatilised in the oxyhydrogen flame are silicon, titanium, vanadium, tungsten, platinum, &c., and these have not been sought for.

The range of spectrum examined is extensive, and lies between wave-lengths 6000 and 3200, and lines capable of being photographed were carefully observed. It will be noticed that in the tabulated statement on next page, after the symbol of the element, an index number from 1 to 9 shows the relative strength of the lines, the figure 1 indicating the weakest, and 9 the strongest appearance of the same lines in the several spectra. In the case of the principal constituents of the meteorites this is unnecessary, as lists of the lines measured are given, but where only two or three lines are visible, the substances being in minute proportions, the index figures serve a very useful purpose. Symbols in italics indicate traces only. The tabulated statement clearly shows the elements which are present, with variations in the composition of the different specimens.

The lines were identified by measurements made on the photographs, and wave-lengths were obtained from curves based on Rowland's Standard, the particular wave-lengths quoted being those of Kayser and Runge. Lists of the lines of iron, nickel, cobalt, sodium, potassium, rubidium, gallium, copper, silver, and lead are given. A calcium line was recorded in all specimens, and the *bands of magnesia* in all the stony meteorites.

We were at first inclined to doubt whether calcium, sodium, and potassium, were really constituents of the meteoric irons, but the lines of the alkali metals, which are very weak, were proved to belong to the metallic iron by burning it without having recourse to a support of any kind, and thus the spectrum observed was the same as that obtained by burning filings of the metal on supports. A portion of the file used upon the metal was also burnt, and this showed a composition differing from that of the meteoric irons, since it contained manganese, but no nickel, cobalt, or gallium.

THE COMPOSITION OF METEORIC IRONS, SIDEROLITES, AND METEORITES.

Country and Date.	Calcium.	Iron.	Nickel.	Cobalt.	Chromium.	Gallium.	Lead.	Manganese.	Silver.	Copper.	Sodium.	Potassium.	Rubidium.
Meteoric Irons.													
1. Virginia (1) (b),	Ca	Fe	Ni	—	—	Ga 2	—	—	Ag 1	—	Na	—	Rb
2. Virginia (2). Royal College of Science Museum, Dublin (a)	Ca	Fe	Ni	Co	—	Ga 1	Pb 4	—	Ag 1	Cu 2	Na	K	Rb
3. Iron, with troilite, Arva, Hungary (a),	Ca	Fe	Ni	Co	—	Ga 3	Pb 6	Mn	Ag 1	Cu 4	Na.	K	Rb
4. Coahuila Mexico. Fell, 1866 (b),	Ca	Fe	Ni	Co	—	Ga 1	Pb 2	—	Ag 1	Cu 1	Na.	K	Rb
5. Toluca, Mexico. Found, 1784 (b),	Ca	Fe	Ni	Co	—	Ga 3	Pb 1	—	Ag 1	Cu 2	Na.	K	Rb
6. Cañon Diablo, Yarapia County, Arizona. Found, 1891 (b),	Ca	Fe	Ni	Co	—	Ga 2	Pb 4	Mn	Ag 1	Cu 4	Na.	K	Rb
7. Thunda, Windorah, Queensland. Fell Dec., 1886 (b),	Ca	Fe	Ni	Co	—	Ga 1	Pb 2	—	Ag 1	Cu 2	Na.	K	Rb
Siderolites.													
8. Atacama, Chili. Found, 1858 (a),	Ca	Fe	Ni	Co	—	Ga 1	Pb 4	?	Ag 3	Cu 3	Na.	K	Rb
9. Estherville, Emmet County, Iowa. Fell, May 10th, 1879 (b),	Ca	Fe	Ni	Co	Cr 1	—	Pb 2	?	Ag 1	Cu 2	Na.	K	Rb
10. Imilac, Atacama, Chili. Found, 1829 (b),	Ca	Fe	Ni	Co	—	—	Pb 1	?	—	Cu 2	Na	K	Rb
Meteorites.													Magnesium. MgO
11. Alfanella, Lombardy. Feb. 16th, 1883 (a),	Ca	Fe	Ni	—	Cr 3	Ga	Pb 1	Mn	Ag 1	Cu 2	Na.	K	MgO
12. Pultusk. January 30th, 1868 (a),	Ca	Fe	Ni	—	Cr 2	—	Pb 1	Mn	Ag 2	Cu 2	Na.	K	MgO
13. Mocs, Transylvania (a),	Ca	Fe	Ni	—	Cr 3	—	Pb 1	Mn	Ag 1	Cu 2	Na.	K	MgO

(a) Specimens from the collection in the Royal College of Science, Dublin.
(b) Specimens purchased from Messrs. James R. Gregory & Co., 1, Kelso-place, Kensington, London.

It is difficult to determine whether rubidium is present on account of the proximity of two iron lines, but the more refrangible is the stronger of the rubidium lines; it is exactly the reverse with the iron lines. Their wave-lengths are—rubidium, 4215·72, 4201·98; iron, 4216·28, 4202·15.

LIST OF IRON LINES MEASURED AND IDENTIFIED IN THE SPECTRA
OF METEORIC IRONS : WAVE-LENGTH ACCORDING TO KAYSER
AND RUNGE'S MEASUREMENTS.

λ	λ	λ	λ
5371·60	4045·90	3813·12	3682·35
5330·90*	4005·33	3799·68	3680·03
E 5269·65	3969·30	3798·65	3647·99
5169·09	3930·37	3795·13	3631·62
5110·50	3928·05	3788·01	3618·92
4482·35	3923·00	3765·66	3608·99
4461·75	3920·36	3763·90	3587·10
4427·44	3906·58	3758·36	3586·24
4415·27	3899·80	3749·61	N 3581·32
4404·88	3895·75	3748·39	3570·23
4383·70	3887·17	3745·67	3565·50
4376·04	3878·82	3743·45	3558·62
4325·92	3872·61	3737·27	3526·50 **Ni here.**
G 4307·96	3867·33	3735·00	3521·56
4294·26	3860·03	3732·54	3513·91
4271·30	3856·49	M { 3727·78	3497·92
4250·93	3850·11	{ 3727·13	3490·65
4216·28	3840·58	3722·59	3476·75
4202·15	3834·37	3720·07	3475·52
4143·96	3826·04	3709·37	3465·95
4132·15	3824·58	3708·03	O 3441·07
4071·79	L 3820·56	3707·18	3440·69
4063·63	3815·97	3687·77	

LINES OF NICKEL IN METEORIC IRONS : WAVE-LENGTHS ACCORD-
ING TO LIVEING AND DEWAR.

λ	λ	λ	λ
3857·8	3565·7	3461·1	3390·4
3806·6	3547·5	3457·9	3380·0
3783·6	3523·9	3452·3	3373·3
3775·0	3519·1	3445·7	3371·3
3618·8	3514·4	3436·7	3368·9
3612·1	3509·7	3433·0	{ 3365·4 } Appear as
3609·8	3492·3	3423·1	{ 3365·1 } one line.
3597·0	3483·1	3413·8	3319·7
3571·2	3471·9	3412·9	3315·1

LINES OF COBALT IN METEORIC IRONS : LIVEING AND DEWAR'S
WAVE-LENGTHS.

λ	λ
4119·4	3553·6
3995·4	3529·9 } Very strong.
3575·7	3529·0 }
3575·3	3526·9 Possibly two
3569·7	3502·2 lines.

* Not identified on Kayser & Runge's map : possibly it is 5330·15, but in our
spectra there is a diffuse band of rays hereabouts, and apparently several feeble line
or edges of bands, which are difficult to measure.

LINES OF THE ALKALI METALS IN METEORIC IRONS: KAYSER AND RUNGE'S MEASUREMENTS.

SODIUM.	POTASSIUM.	RUBIDIUM.
λ	λ	λ
$\left.\begin{matrix} 5896\cdot16 \\ 5890\cdot19 \end{matrix}\right\}$	$\left.\begin{matrix} 4047\cdot36 \\ 4044\cdot29 \end{matrix}\right\}$	4201·98
3303·07		4215·72

LINES OF OTHER METALS IN METEORIC IRONS.

GALLIUM.	COPPER.	SILVER.	LEAD.
λ	λ	λ	λ
4171·8	3274·09	3382·98	4057·97*
4032·7	3247·65	3280·80	3683·60
			3639·70

A calcium line was observed, wave-length 4226·91. This was believed to be caused by dust. There is an iron line at 4227·60 (K. & R.), but it does not appear in flame spectra. In the meteoric irons from Arva, Hungary, in which there is troilite, and in the specimen from Cañon Diablo, Arizona, there is a trace of manganese. The lines just visible are those with wave-lengths 4033 and 4030 (Liveing and Dewar's numbers are 4032·0 and 4029·5).

The nickel and iron lines are strong in all the specimens. The alkali metals are weak, potassium being found in traces only. These spectra disclose a marked difference between meteoric iron and telluric metal, not only in the presence of a large proportion of nickel in the former, but in the absence of manganese, an element which is invariably contained in the latter.

The presence of gallium in variable proportions in the iron meteorites is remarkable. The only one in which its occurrence was at first doubtful was that from Thunda, Windorah, Queensland. Cobalt occurs in all specimens except in one from Virginia, but it does not appear in the meteoric stones.

The meteoric stones all contain chromium in variable proportions, and manganese in traces only.

The meteorite from Atacama consists of a honeycombed mass

---

* This line is shown as 4357 in the plate 7, Phil. Trans., vol. 185, 1894, by an error of the engraver.

of iron, the spaces being filled with a yellow crystalline mineral (olivine?) which was examined separately from the iron, and found to contain the following constituents, the bases being separated from the silica.

COMPOSITION OF THE NON-METALLIC PORTION OF THE IRON METEORITE FROM ATACAMA.

Alkali and Alkaline Earth Metals.—Sodium, potassium, magnesium, calcium, and a trace of strontium present as oxides or silicates.

Heavy Metals.—Iron, nickel, chromium, copper, silver, lead, and a trace of manganese as oxide or silicates.

Professor Norman Lockyer has examined the photographic arc spectra of iron meteorites, Phil. Trans., vol. 185, p. 1023, using as poles pieces of the meteoric irons from the British Museum, known as the Nejed and Obernkirchen meteorites. The range of spectrum was from about 5892 (D) to 3933 (K). In addition to iron the following substances were declared to be certainly present:—Manganese, cobalt, nickel, chromium, titanium, copper, barium, calcium, sodium, and potassium. Others were said to be probably present, namely, strontium, lead, lithium, molybdenum, vanadium, didymium, uranium, tungsten, yttrium, osmium, and aluminium.

The general conclusions arrived at were that the two meteorites agreed very closely in composition, that there was a very considerable similarity between the spectra of the meteorites and that of the Sun, the lines having the same relative intensity as those in the solar spectrum. The presence of copper was supposed to be probably due to copper wire being used to bind the pieces of iron to the poles of the arc lamp, as neither flame nor spark spectra confirmed the presence of copper. It may here be remarked, however. that the most prominent lines in the spectrum of copper lie in a region far beyond K in the ultra-violet, and were therefore not within Lockyer's range of observation, when produced either by arc, spark, or flame. There were 43 lines for which no origin was suggested, 29 being apparently coincident with lines in Kayser and Runge's iron spectrum. It was shown that the chief chemical differences between the two meteorites was a preponderance of

calcium in the Nejed meteorite, and of nickel, barium, and strontium in that from Obern Kirchen. A line at 4171·2 is described as "unknown," and one at 4031·4 is doubtfully ascribed to iron. The former is certainly, and the latter probably, a gallium line, wave-lengths 4171·8 and 4032·7.

The substances which yield spectra in the oxyhydrogen blow-pipe, capable of being photographed are those which are easily volatilised at a temperature of about 1800° C., as one of us has already shown ("Flame Spectra at High Temperatures, Part I., Oxyhydrogen Blow-pipe Spectra," Phil. Trans., vol. 185, p. 161, 1894), and they form a very large proportion of the metallic elements and their compounds. When examined by this method over a wide range in the ultra-violet, most substances yield characteristic spectra.

Conclusions.

1. The composition of different meteoric irons is very similar, though the proportions of the constituents differ to some extent.

2. We find that copper, lead, and silver are common constituents of meteoric irons, and that they occur in variable proportions. We have already shown that this is the case with iron ores of different varieties, and different kinds of manufactured irons.

3. Gallium is a constituent in varying proportions of all meteoric irons, but not of all meteorites. It occurs in one of the siderolites we have examined.

4. Sodium, potassium, and rubidium, are constituents of meteoric irons, but only in minute proportions.

5. Chromium and manganese are found in meteoric stones, but not in the irons, though very minute traces of manganese have been detected in two of our specimens.

6. Nickel is found as a principal constituent in all meteorites, meteoric irons, and siderolites. Cobalt occurs in the two latter varieties only.

The chief points of difference between telluric and meteoric iron is the absence of nickel and cobalt in any considerable proportion from the former, and the presence of manganese; while meteoric irons contain nickel and cobalt as notable constituents, and, except in minute traces, manganese is absent.

DESCRIPTION OF PLATES.

———

The three Plates reproduce the flame spectra of six Meteoric Irons and three Siderolites. Along the middle of each flame spectrum is a spark spectrum of two alloys, which yield lines of air, cadmium, lead, tin, bismuth, and silver, the wave-lengths of which are accurately known. The wave-lengths of the lines in the flame spectra are easily determined from a curve of wave-lengths drawn from the lines in this spark spectrum.

The principal lines of the elements present cannot be marked on every spectrum, but they are indicated by the symbols or names of the elements on different plates, thus :—

On Plate XXII. : sodium, calcium, lead, nickel, rubidium, potassium, silver, gallium, and copper. On Plate XXIII. : cobalt and iron. On Plate XXIV. : manganese.

Plate XXII.—Meteoric Irons :—

Spectrum 1. Virginia (1).
,, 2. Virginia (2).
,, 3. Arva, Hungary.

Plate XXIII.—Meteoric Irons :—

Spectrum 1. Tolucca, Mexico.
,, 2. Cañon Diablo, Arizona.
,, 3. Thunda, Queensland.

Plate XXIV.—Siderolites :—

Spectrum 1. Atacama, Chili.
,, 2. Estherville, Iowa.
,, 3. Imilac, Chili.

LXIX.

ON THE MOUNTING OF THE LARGE ROWLAND SPECTRO-METER IN THE ROYAL UNIVERSITY OF IRELAND. By W. E. ADENEY, D.Sc., F.I.C., Curator in the Royal University, AND JAMES CARSON, A.R.C.Sc.I., C.E.

THE working parts of this instrument were obtained from Mr. J. A. Brashear, of Allegheny, United States of America. They consist of two interchangeable inverted ⊥ steel rails, each of about 23 feet in length, and each having the upper edge planed to an inverted ∧ section, with top truncated.

These rails were supplied with saddles of cast iron, into which the rail was fixed, and which were provided with levelling and lateral adjustment screws.

One of these saddles takes one end of each rail at right angles, one to the other, and also carries the mounting for the slit.

The "diagonal beam" is an iron girder consisting of a tube about 3″ diameter (T, fig. 1), trussed with $\frac{3}{8}$″ rods (R, fig. 1), the struts being placed at angles of 120° round the tube. Fixed to each end of the tube is a cast-iron palm (J, fig. 1), which is provided with a small range of adjustment in the direction of the length of the girder.

These palms are provided with vertical axes, which form the connexion with the carriages (I, fig. 1), which run on the rails.

On the one palm is fixed the grating holder (G, fig. 1), and on the other the camera. These parts are similar in structure to those described and illustrated by Ames in the Astro-Physical Journal, p. 28, January, 1892.

The concave grating, which was also obtained through Mr.

Brashear, has a focal length of 21·5 feet; the ruled space is about 6 inches long, bearing 14,438 lines to the inch. The spectra on one side of the grating are all bright; the first order on the other side is somewhat brighter than the others. Mr. Brashear remarks, in a letter to one of us, that "Professor Rowland states all the lines are clear and sharp," and adds, "You are very fortunate in getting this grating, for no one knows when we will get another."

Our own experience with the grating fully corroborates these remarks. The definition of the spectral lines afforded by it is remarkably fine; and we feel it due to Mr. Brashear to express here the thanks, which have been conveyed to him by letter, for the trouble and care he has so courteously taken to furnish this University with such a very fine instrument.

For various reasons we decided not to erect the spectrometer in a dark room, but determined rather to set it up in a room open to day- and sun-light, and to endeavour to devise the light-tight connexions between the working part of the instrument, which then become necessary for photographic, as well also as for eye, observations.

A raised floor, 30 feet by 30 feet, and about 9 feet high, was built at one end of the Physical Laboratory of the University, the floor being supported on steel girders, the ends of which were built into two opposite side-walls of the laboratory, while the central portions were supported by steel columns resting on concrete foundations.

The spectrometer was mounted on this raised floor in the following manner :—

Two red deal beams, each 12″ by 3″, and of sufficient length to carry the steel rails, were mounted true and level on cast-iron standards bolted to the floor.

To these were bolted the saddles mentioned above, and on these were fixed the rails. The latter were very carefully adjusted, so as to be exactly level, straight, and at right angles to one another.

The beam on which the grating rail H was mounted also served as a basis for a light-tight wooden structure running along its whole length, and completely enclosing both the rail and grating.

Fig. 1 shows this structure in section, with the rail, carriage, and grating indicated in position inside.

Fig. 1.
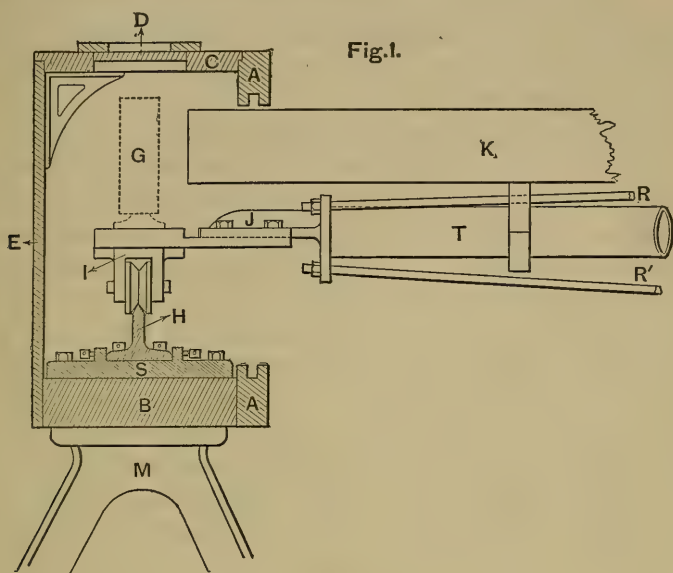
M represents a cast-iron standard.

B	,,	the beam 12″ by 3″.
S	,,	the saddle.
H	,,	the rail.
E	,,	sheeting of $\frac{3}{8}$″ cedar wood.
C	,,	framed top fastened to E and supported by brackets. The panels in this are represented by movable lids (D).

AA are pieces secured, one to B and the other to C, and grooved for the reception of sliding doors, each about 2 feet wide, by means of a series of which the side of the rectangular box could be closed in from either end, making the whole completely light-tight. This construction was necessary, inasmuch as the girder passed out through this side, and at a varying angle, and different position, with every movement of the grating carriage along H, and with the corresponding movement of the camera along the other rail H′.

3 G 2

One end of this rectangular structure or box was permanently closed, and a short piece of brass tube made to slide through a hole in the end at the proper height for the slit. This brass tube was supplied with a boxwood flange fitting light-tight against the slit mounting, so that all the adjustments of the latter were outside the wooden rectangular box.

The other end was closed by a sliding door.

A light-tight connexion had now to be established between this wooden box and the camera at the other end of the girder, and inasmuch as the girder not only moved from one end of the tube to the other along the rail H, but at every new position on the rail made a different angle with it, it was impossible to accomplish this connexion by anything in the nature of a bellows. After much consideration the following method was decided on, and works admirably in practice :— On the iron tube of the girder was fixed, by means of wooden supports and clamps, a wedge-shaped rectangular tube of wood, a little wider than the grating at one end, and the width of the camera at the other, and about four inches deep. Part of this is shown in fig. 1 as K. The end came to within about $1\frac{1}{2}''$ inches from the face of the grating G.
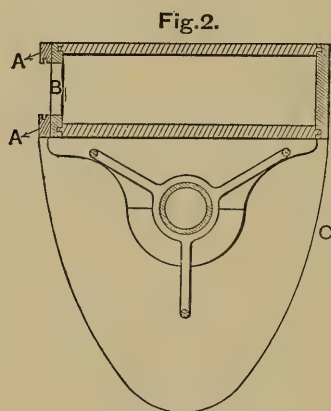
Fig.2.

Fig. 2 shows a section, which represents the construction for about one-half of its length from the grating end, the remainder being without the grooved slides (A). The tube is shown in plan in fig. 3.

The opening (B) was in that side of the tube nearest the rail, and was necessary when the camera was close up to the slit; since the light from the slit would otherwise be cut off from the grating by the angle of the tube coming between them, as shown in fig. 3 in plan.

Fig.3.
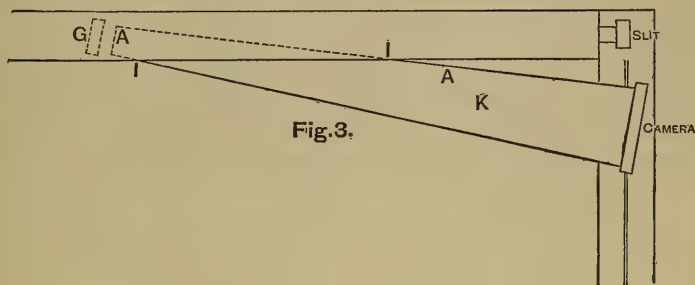
An arrangement for wholly or partially closing this opening at will was provided, in the shape of a door sliding in the grooves AA.

In order to close up the space below the tube K, inasmuch as the sliding doors referred to as moving in the grooves AA in fig. 1 could not come beyond the points of intersection of the tube K with their plane—namely, II in fig. 3—and inasmuch also as the lower grooved piece (A, fig. 1) had to be at sufficient distance below T to clear the lowest point of the tie-rod R, the simplest way that could be thought of by the authors was to suspend a loose bag or tube of felt cloth from the lower edges of the sides of K, letting it hang down and enclose the girder and its tie-rods.

This is shown at c in fig. 2, but is supposed to have been removed in fig. 1, so as to show the tube and tie-rods.

The outer end of the bag, or the end nearer the camera, was closed up, and the other came well within the plane of AA, fig. 1.

This was found to answer admirably, and by the aid of a cloth thrown across K, and loosely tucked in against A on the top, and the sliding doors and the felt bag at the sides, no difficulty has been experienced in obtaining a perfectly light-tight joint in all positions of K. The camera is connected to the other end of K by a few inches of bellows, which allows for the focussing adjustment.

The spectrometer, mounted in the manner here described, has now been in use for more than a year, and has been thoroughly tested. It has been found most convenient both for making eye-piece observations, and for taking photographs; it has also been found completely light-tight. In proof of this last statement, we may mention that we have exposed rapid photographic plates in the camera of the instrument for upwards of six hours, on bright sun-lit days, during the course of an investigation we have been, and are at present, making, in conjunction with Professor Hartley, F. R. S., upon the ultra-spark spectra of the elements, and have experienced no difficulty whatever from " fogging."

LXX.

NOTES ON CERTAIN ACTINIARIA. By DR. KATHERINE
MAGUIRE. (PLATE XXIVa.)

(COMMUNICATED BY PROF. A. C. HADDON.)

(a).—THE ANATOMY OF PHELLIA SOLLASI, HADDON.

THROUGH the kindness of Professor Haddon I was given four
specimens of this species to examine; they were brought by Pro-
fessor Sollas from Funafuti in 1896. The specimens were pre-
served in spirit, and the colour, of which no note had been taken,
was completely lost.

Form.—The preserved specimens are more or less cylindrical;
one is barrel-shaped; none of them are completely retracted. The
tentacles are set in three rows on a circular disc; they are simple,
conical, and blunt at the apex, from which radial longitudinal
striæ run down the wall. The arrangement is entacmæous; the
number in one specimen is forty-eight, of which the six inner are
larger than the others. In another specimen there are fifty-four
tentacles, of which the twelve inner are the largest. The body-
wall is opaque. The surface of the column is transversely grooved;
but there are no warts, tubercles, nor acrorrhagi; the pedal disc is
well marked in two specimens. The mouth is linear; in two
specimens the gullet is everted, showing two gonidial grooves.
In the smallest specimen whitish threads hanging from the mouth
proved to be acontia.

Size.—The length of the preserved specimens is 15–23 mm.;
the average diameter of the column is 8–10 mm.

Internal Anatomy.—On longitudinal section, the mesoglœa of
the lower three-fourths of the body-wall is seen to be much thicker

than the upper one-fourth.   The longitudinal muscles of the primary mesenteries form well-marked swellings which are easily seen by the naked eye.

Of the two specimens examined with the microscope, one (the smallest) was stained in borax-carmine, imbedded in paraffin, and cut transversely in series.   The larger specimen was cut in two, the lower half was stained in carmine, and cut transversely, two portions of the upper half were also stained in carmine, and cut longitudinally.

The transverse sections of the larger specimen, through the gullet show two pairs of directives with four pairs of lateral complete mesenteries, making six pairs of primary mesenteries.   There are six pairs of secondaries bearing mesenterial filaments and acontia.   Twelve pairs of tertiaries without filaments, and three pairs of fourth-cycle mesenteries which do not project above the endoderm.   Below the gullet, the number of mesenteries of the fourth cycle increases, and *ovaries are found only on the primary mesenteries including the directives.*

Lower down, the number of fourth-cycle mesenteries is further increased.   Mesenterial filaments and acontia are present along
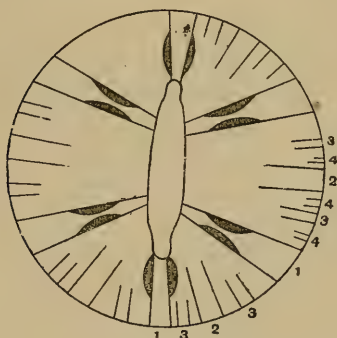
Fig. 1.

Phellia Sollasi.—The œsophageal region of the large specimen.
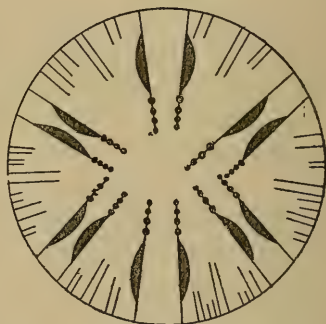
Fig. 2.

Phellia Sollasi.—The same below the œsophagus, showing gonads on primary mesenteries.

with the gonads on the primary mesenteries.   In the lower sections, the lateral primary mesenteries incline towards each other, but do not fuse.

The small specimen is not so well preserved.   It was protruding acontia through its mouth, and the gullet is everywhere

filled with a mass of partly broken down acontia. The number and arrangement of the mesenteries are almost identical with those of the larger specimen. But below the gullet, one of each of the two pairs of lateral primary mesenteries leans over towards the corresponding adjacent mesentery on the same side (that furthest from the directives). Lower down, these mesenteries fuse completely, forming a lateral chamber on each side of the animal. The primaries and secondaries bear mesenterial filaments and acontia. There are no gonads in this specimen. In both specimens, the muscles have the usual Hexactinian arrangement. The retractors are well developed on the primary mesenteries, forming a well-marked pennon. The parieto-basilar muscle is fairly developed.
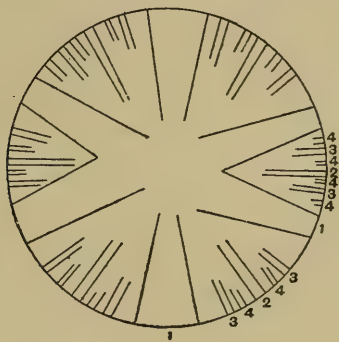
Fig. 3.

Phellia Sollasi.—Small specimen, below the œsophagus, showing fusion of lateral primary mesenteries.

Sphincter.—The sphincter extends through about the upper third of the body-wall.

It is mesoglœal, occupying at its commencement the inner half of the mesoglœa which is here very thick; though the muscle has sunk into the mesoglœa, it is not surrounded by it, but is still directly continuous with the endoderm, where the body-wall is thick. Higher up where the wall is thinner, the muscle is much reduced, only a few strands, which are separated from the endoderm, being visible. There is a stronger portion forming a small prominence in the body-wall at the base of the outer tentacles; here the muscle occupies almost the whole thickness of the mesoglœa, but the lower part, where the body-wall is thick, is much the best developed. The endodermal circular muscle persists inside the sphincter.

Histology.

Ectoderm.—There is a thin cuticle on the lower three-fourths of the capitulum; it is absent on the thin upper part of the wall. The ectodermal surface is everywhere exceedingly irregular, giving rise to numerous ectodermal lacunæ in the mesoglœa. The general character of the ectoderm shows nothing unusual. On the tentacles, there are numerous stinging cells, both thin and thick walled. Ectodermal muscles are only present in the tentacles and disk, where they are well marked.

No cinclides could be seen.

Mesoglœa.—The mesoglœa of the body-wall shows an inner deeply stained dense layer; made up of fibres running both transversely and longitudinally, and an outer layer not stained so deeply, made up of fine fibres which cross each other, forming a loose reticular structure. The mesoglœa of the tentacles contains numerous cells. The ectodermal muscles, which are very well marked, sink somewhat into the mesoglœa, but are not enclosed by it, and cannot be called mesoglœal.

A few strands of muscle are prolonged from the sphincter into the mesoglœa of the disc, but in other places the mesoglœa of the disc is thin, and there is no mesoglœal muscle.

In all sections of the upper part of the body-wall, irregularly rounded bodies of varying size are seen, mainly in the mesoglœa, but in some places in the endoderm. These bodies stain deeply with carmine, and are made up of fine granules, most of which are very small and highly refracting, a few of them are larger, and may be also highly refracting, but are occasionally much darker than the other granules. Some of the smaller bodies seem to be made up of a few of these granules surrounded by dense deeply stained mesoglœa, but other small ones do not differ in any way from the larger and presumably older bodies. I have described these with the mesoglœa, as they are a striking feature in sections of the body-wall, but they also occur, though not so frequently in the endoderm. The mesoglœa of the gullet and septa shows no special features; the mesoglœal strand of the acontia is almost circular.

Endoderm.—The endoderm is of the usual type; gland cells are not very abundant. Algæ are everywhere present. The

endodermal muscle of the body-wall is well developed; that of the tentacles and disk is not well marked.

Mesenteries.—The arrangement of the muscles has already been described. The central glandular streaks of the mesenterial filaments are well developed; they contain large glandular cells both granular and homogeneous, and thick walled stinging cells. The ciliated lateral streaks are poorly developed. The acontia, which are borne like the mesenterial filaments by the primary and secondary mesenteries only, are fairly abundant. In transverse section, they are nearly circular; they show numbers of very large thick-walled stinging cells, and a few fine granular gland-cells.

The gonads are found on the first cycle of mesenteries, between the retractor muscles, and the mesenterial filaments; they have the usual structure.

Two points of interest to be noted in this species are the coalescence of some of the mesenteries, and the granular bodies in the mesoglœa and endoderm. With reference to the coalescence of mesenteries, this condition has been described and figured by R. Hertwig (Report on the " Challenger " Actiniaria, 1882, p. 83, plate viii., fig. 2) in the primary mesenteries of *Chitonanthus* (*Phellia*) *pectinata*.[1] Fusion of the secondary mesenteries is described by the same author (*loc. cit.*, p. 37, pl. viii., fig. 5) in *Tealia bunodiformis*. In both these cases, fusion occurred between mesenteries of the same pair, not of different pairs as in this species.

Hertwig regards it as a temporary condition; and it seems probable that it must be so, as in *Phellia Sollasi* the primaries are alone fertile; and in the larger specimen containing gonads, the mesenteries were not fused. Coalescence of primary mesenteries (directives) with each other, and with several pairs of secondary mesenteries, has been described and figured in *Bunodes thallia* by G. Y. and A. F. Dixon (*Proceedings*, Roy. Dubl. Soc., 1889).

A similar condition has also been noted by G. H. Parker in *Metridium marginatum* (Bull. Mus. Comp. Zool., Cambridge, Mass., xxx., 1897, p. 267).

---

[1] This species is certainly not a Phellia, as Hertwig supposed. Haddon regarded it as a Hormathia; but McMurrich (Proc. U. S. Nat. Mus., 1893, pp. 189, 209) places it in his new genus Chitonanthus.

As regards the granular bodies, Hertwig (*loc. cit.*, p. 82, pl. viii., fig. 1) makes the following statement about *Chitonanthus pectinata*, " in it (the mesoglœa), there are small roundish concrements which are strongly coloured by carmine, and the structure of which recalls that of granules of starch ; they are made up of indistinct concentric layers, frequently appear in section like a figure 8, and are limited to the superficial layer of the mesoderm." He makes no conjecture as to their nature.

It seems likely that the granular bodies found in *Phellia Sollasi* may be of the same nature as those in *Chitonanthus pectinata ;* they are not identical with them, as they are not in the least like the figure, and are not apparently made up of concentric layers, though a different method of preservation might make a difference in their appearance. The only other references to such structures that I can find are in McMurrich ("Albatross" Report, Proc. U. S. Nat. Mus., 1893, p. 177), where he describes " granular, spherical, or oval bodies in the ectoderm of the disc of *Sagartia lactea*"; they stained deeply, and he believed them to be glandular ; he gives no figure, but the description, though not the situation, resembles the bodies in *Phellia Sollasi.* S. J. Hickson (Quart. Journ. Micr. Sci., vol. 37, pt. 4) describes and figures dark homogeneous bodies seen in and among strands of endoderm cells ; in the mesoglœa of Alcyonium, he thought they were probably parasitic sporozoon.

I should be inclined to regard the bodies seen in *Phellia Sollasi* as due to a parasite more likely vegetable than animal.

(*b*).—The Anatomy of Paranthus chromatoderus.

Entacmœa chromatodera, sp. n., Schmarda, 1852, p. 15.
Actinia chromatodera, Schm., Heller, 1868, p. 19.
Paractis rugosa, sp. n., Andres, 1880, p. 314.

Through the kindness of Professor Haddon, I was given six specimens of this species to examine.

External Characters.—These are described from the living animal by Andres, Le Attinie, 1884, p. 256. The specimens I examined were preserved in alcohol ; the colour is lost. Size: height 30–40 mm. ; average diameter of column 12–18 mm. One specimen is completely retracted. The shape of most of the specimens is cylindrical ; one is urn-shaped.

The surface of the column is smooth. The ectoderm is transparent, showing the insertion of the mesenteries, and the gullet which reaches about half way down the column.

The tentacles are arranged on a circular disc in about four cycles; they are very numerous, nearly 200 in one specimen, small conical, all similar. The mouth is an elongated slit; there are two gonadial grooves. The pedal disc is well marked in most of the specimens.

One specimen was stained in carmine, imbedded in paraffin, and cut transversely. Sections through the gullet show two pairs of directives with four pairs of complete lateral mesenteries, making altogether six primary mesenteries, all of which are sterile.

There are six pairs of secondary mesenteries bearing ovaries and mesenterial filaments. Twelve pairs of tertiary sterile mesenteries. Twenty pairs of sterile mesenteries of the fourth cycle; these are very small, and not raised above the endoderm (fig. 5).

Sections below the gullet show the same arrangement; the primaries bear mesenterial filaments, but no gonads. The number of mesenteries is the same. The shape of the mesenteries was a good deal affected by pressure, the specimen being distended by ova; but there is no doubt that some pairs both of primary and secondary mesenteries are of unequal length.

A second specimen was also cut transversely, showing the same number and arrangement of the mesenteries as the former; *but in this specimen the primaries, including the directives, were fertile*; and some pairs of the secondary mesenteries (but not all) seemed to be also fertile: mesenteries of the third and fourth cycles as in the former specimen.

Sphincter.—The sphincter (fig. 4) is present in the upper part of the column only; it is mesoglœal, occupying the whole thickness of the mesoglœa, and ceasing abruptly at the oral disc. It does not taper much at its lower extremity, but is of the same width throughout.

Ectoderm.—There is no cuticle. The ectoderm of the column and disc is of the usual type. There is no ectodermal muscle on the column. The ectodermal muscles of the tentacles are well developed; that of the disc is fairly developed. There are numerous thin-walled stinging cells in the ectoderm of the tentacles; thick-walled stinging cells are not so common; in other parts of

the ectoderm, these cells are not numerous. The ectoderm of the gullet contains the usual gland-cells.

Mesoglœa.—The mesoglœa is everywhere rather thin. That of the column is dense, made up of fibres running both circularly and longitudinally; it stains very deeply with carmine. There are no mesoglœal muscles except the sphincter. The mesoglœa of the mesenteries also stains deeply.

Endoderm.—The endoderm is of the usual type. Zooxanthellæ are everywhere present.[1] The endodermal circular muscles of the column and tentacles are well marked. The muscles of the mesenteries have the usual hexactinian arrangement. The retractors form a well-marked pennon on the primaries and secondaries. The parieto-basilar muscle is present on the mesenteries of the first and second cycles. Mesenterial filaments are borne by the primaries and secondaries; the glandular streaks are best developed; they contain many thick-walled stinging cells as well as gland-cells. The filaments were, on the whole, not numerous or well developed; but both the specimens examined were distended with ova. No acontia are present. The ovaries are of the usual structure, and contain numbers of nearly mature ova.

P. chromatoderus is the only representative of the genus
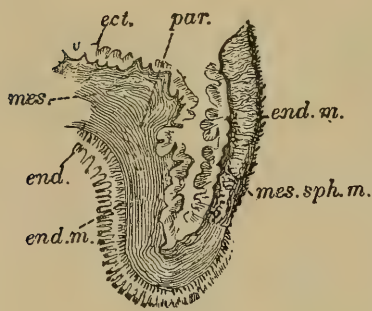
Fig. 4.

Paranthus chromatoderus.—Vertical section of upper part of column-wall, showing mesoglœal sphincter, and part of parapet. (For Lettering see p. 731.)

Paranthus, which was established and placed with the Paractidæ by Andres on external characters only (" Le Attinie," 1884). The Paractidæ have been variously defined by Hertwig. Report on the Actinaria ("Challenger" Expedition), 1882, p. 41; Andres, " Le Attinie," 1884, p. 255; Danielssen, " Actinida" (Norske Nordhavs. Expedit.), 1890, p. 8; Carlgren, " Studien über Nordische Actinien," ɪ., 1893, p. 64; McMurrich, Report on the Actiniæ ("Albatross" Expedition), Proc. U. S. Nat. Mus. xvi., 1893,

---

[1] I notice that Simon (Beitrag zur Anatomie u. Systematik der Hexactinien, Inaugural Dissertation der Universität München, 1892, p. 45) says, in his definition of the Paractidæ, " Zooxanthellæ in this family have so far not been recognised."

p. 160.   The latter simply separates the Paractidæ from the Sagartidæ by the absence of acontia; and with this definition, *P. chromatoderus* seems to agree very well.

Fig. 5.

Paranthus chromatoderus.—Transverse section through part of œsophageal region of column.   (For Lettering see p. 731.)

(c).—The Anatomy of Actinia equina (Linn.)

var. Mesembryanthemum.

So many figures and descriptions of the external characters of this Actinia have been given by Gosse, Andres, and others, that I do not propose to describe anything but the internal anatomy, about which more information is required.

The methods used were the following :—

Some specimens were hardened in formaldehyde four per cent., and examined macroscopically.   This reagent destroys the colour,

but does not make the specimens brittle, so that they could be cut easily without injuring the septa. For microscopic work, one of the specimens hardened in formaldehyde was also used; it had been in the reagent for some weeks, having been fixed in five per cent., and transferred in a few days to a four per cent. solution; it was stained in borax carmine, dehydrated with absolute alcohol, and imbedded in paraffin; this specimen shows the histological details very well, though the ectoderm was not stained as deeply as usual; the cilia were very distinct. It does not seem to have suffered from dehydration in any way, and the cells are not much vacuolated.[1]

One large specimen was fixed and hardened in a mixture of three and a-half per cent. each of bichromate of potash and formaldehyde (this mixture keeps badly) as a fixing reagent; it acts slowly and does not cause very complete contraction. As a hardening reagent for general use, specimens may be left in it for from ten days to a fortnight, and a much longer time may be allowed to elapse without overhardening; the fluid must, of course, be changed from time to time. This specimen was cut up into four, and after three days two parts were transferred to nitrate of silver seventy-five per cent. solution, to try if Golgi's reaction could be obtained. These were afterwards dehydrated with alcohol imbedded in paraffin, and cut; but the chromate of silver had only formed a coating on the outside, though the tissues were in a good state of preservation. Carlgren (1893) also failed to stain Actinia after Golgi's method. The two other pieces which had been hardened for about a fortnight in bichromate and formaldehyde were washed in water for twenty-four hours, stained in borax carmine, dehydrated for several days in alcohol (in the dark), imbedded in paraffin, and cut—one part longitudinally, the other transversely; this method of hardening is admirable for the histological details; the cilia are unusually well seen (perhaps this is due to the formaldehyde as they are very distinct also in the sections hardened in it). Some specimens were also stained with methylene blue, the living or recently killed animals being put into a solution of ·75 per cent. sodium chloride and methylene blue, and left for twenty-four hours; the specimens were then

---

[1] Some other specimens hardened in formaldehyde did not stain well. I believe prolonged after-treatment with alcohol is advisable to ensure uniform results with formaldehyde material.

fixed in platinic chloride four per cent. solution for twenty-four hours then transferred to alcohol and imbedded in the usual way. The platinic chloride fixes the stain very well; and it had penetrated to the endoderm in the superficial parts, such as the tentacles, but it was mainly taken up by the epithelial cells, and did not show any details of the nervous system.

An adult specimen hardened in four per cent. formaldehyde, and examined macroscopically showed the following arrangement of the mesenteries. In section through the gullet, there are altogether twenty-four pairs of complete mesenteries, including two pairs of directives; from embryological considerations, it is obvious that every fourth complete pair of mesenteries from each directive must be a pair of primaries. The secondaries and tertiaries can be determined in the same way.

Thus of the complete mesenteries there are :—

Primary, six pairs.
Secondary, six pairs.
Tertiary, twelve pairs, making twenty-four pairs of complete mesenteries.

Of incomplete there are :—

Fourth cycle, twenty-four pairs.
Fifth cycle, thirty-eight pairs, making sixty-two pairs of incomplete mesenteries, eighty-six pairs in all.

In the lower half of the column, the mesenteries were the same, except for the fifth cycle, of which there were apparently only thirty-six pairs. All mesenteries, except the fifth cycle, bear mesenterial filaments. In a large adult examined microscopically, there are in sections through the gullet :—

Primary mesenteries, 6 pairs (2 directives);
Secondary   ,,   6 pairs;
Tertiary   ,,   12 pairs, making twenty-four pairs of complete mesenteries;
Fourth cycle, -   24 pairs;
Fifth cycle,   -   24 pairs;

making forty-eight pairs of incomplete mesenteries, seventy-two pairs in all. Lower down the number of fifth-cycle mesenteries was, as far as they could be counted, the same. All mesenteries bear mesenterial filaments, except those of the fifth cycle.

Though both these specimens contained numbers of embryoes, neither of them had attained the full number of the fifth cycle of mesenteries.

In the specimen examined microscopically, the fifth cycle seemed to be developing from one pair of directives, where all the cycles were complete, towards the other where the fifth cycle was undeveloped. This was not so clear in the macroscopic specimen, though the cycles near one pair of directives were all complete, while one of the fifth was wanting to one side of the other pair of directives.

Sphincter.—The sphincter is a diffuse endodermal one, being merely a thickening of the endodermal muscle lying between the marginal spherules and the outer row of tentacles.

Histology.

Ectoderm.—There is no cuticle. The nervous layer is everywhere well developed. The usual gland-cells are present. Thread-cells are very abundant in the tentacles and marginal spherules; they are scarce elsewhere. The ectodermal muscles of the oral disc and tentacles are well developed : these are the only places where ectodermal muscle fibres occur. The gullet has the usual structure.

The marginal spherules are placed just outside the sphincter. In longitudinal sections they are often irregularly quadrangular, the external angle being the most acute. The ectoderm is much thicker here than on other parts of the disc. In some sections it can be seen to form three layers :

(*a*). A layer of delicate fibres with a few scattered small cells.

(*b*). A layer two or three rows deep of fusiform granular cells very closely set ; there are also a few thread cells and a few supporting cells.

(*c*). The outer layer, one row of cells deep, consisting almost entirely of thick-walled thread-cells set evenly side by side ; there are also a few fusiform granular cells like those of layer (*b*). At the edges of the spherule, the ectoderm is much like that of the disc, only somewhat thicker, and with more numerous thread cells. The mesoglœa and endoderm have the usual structure.

Mesoglœa.—The mesoglœa is not very thick; it never contains muscle; it is fairly homogeneous. Sections hardened in formaldehyde show numerous cells.

Endoderm.—The endoderm has the usual structure. It contains large quantities of gland-cells, both granular and homogeneous, especially on the surfaces of the mesenteries. That lining the column and the tentacles contains numbers of algæ. The endodermal muscle of the column is very well marked, and so are those of the tentacles and disc.

Mesenteries.—The numerous gland-cells on the surfaces of the mesenteries have been already mentioned. The muscles have the usual hexactinian arrangement; the retractors do not form a well-marked pennon, but are distributed fairly evenly along nearly the whole length of the mesenteries. The parieto-basilar muscle is present and forms a well-marked swelling on all the mesenteries, except those of the fifth cycle. It is very close to the body-wall in sections high up, but is much further in lower down. The mesenterial filaments are numerous at all levels of the Actinia. Those in sections through the gullet show the lateral ridges well marked; lower down, these ridges are much lower, and the cells contain numerous algæ. The central streak contains the usual gland-cells, and a few thick-walled thread-cells.

No gonads were developed in any of my specimens, though I examined them both in winter and spring, and many of them were full of embryoes. Milne-Edwards (Hist. Nat. des Coralliares, 1857, p. 240) states:—" The production of well-developed young in the interior of the gastric cavity is a very well-known phenomenon in *Actinia equina*, and it appears to begin before the reproductive organs have arrived at maturity."

Since this Paper was written, I have seen an account of the anatomy of *Actinia equina*, by T. A. Simon (Beitrag zur Anatomie und Systematik der Hexactinien, Inaugural Dissertation der hohen philosophischen Facultät der Universität München zur Erlangung der Doctorwürde, 1892, pp. 42–45). I can corroborate a great deal of what he says, but in some points my specimens seem to have differed from his. In his account of the sphincter, on p. 43, he says: " The strong fibrillar mesoglœa is at its (the sphincter's) site thickened to more than double, so that one can see

something of it with the naked eye." In my specimens, this thickening of the mesogloea at the site of the sphincter is very trifling; indeed, scarcely noticeable. Further on, p. 44, still speaking of the sphincter, he says:—"The mesogloea does not rise as in *A. sulcata* and *Antheopsis roseirensis* into more or less high folds, but preserves an entirely smooth surface towards the epithelium; moreover the muscle fibres grow deeply into it, and appear at times to become wholly mesogloeal. One may regard the singular condition of this sphincter as being in a certain sense a transition or middle stage between an endodermal and a mesogloeal sphincter; the latter is at once attained if one thinks of the base (Fussteil) of the muscular twigs as absent." I can find nothing in any of my specimens, when the sections are vertical, which would justify me in saying that the sphincter in *Actinia equina* is anything but endodermal. Oblique sections either of the sphincter or the tentacles often give the effect of mesogloeal muscle.

Speaking of the ectodermal muscles of the oral disc, on p. 44, he says:—"They attain their greatest height in the middle between the insertion of two septa, and form here in tangential sections through the disc, pretty, rosette-like structures; the radial swellings of the disc apparently rise from these." These "rosette-like structures" are seen in tangential sections of my specimens, but I believe they are due to the sections passing somewhat obliquely through the base of a tentacle of a different cycle from those obviously cut in the section, as on following these "rosettes" through several sections, they pass gradually into sections of tentacles. On p. 45, the statement is made that "zooxanthellæ were observed nowhere in the bodies"; in all the specimens I examined down to embryoes of the 8 + 4 stage, the endoderm is everywhere crowded with zooxanthellæ. I notice, on p. 45, that "all the septa, except the directives, bear gonads"; also that all the septa are covered with mesenterial filaments; it is evident that Simon's specimens were older than mine, as in the largest I was able to examine the fifth cycle of mesenteries bore no filaments, and were incomplete in number. Simon does not state the exact number of fifth-cycle mesenteries found in his specimens, but, as he says "they are regularly arranged" (p. 45), I conclude that they had attained their typical number of forty-eight.

EXPLANATION OF PLATE XXIVₐ.

LETTERING ON THE FIGURES.

dr. mest.,	. .	directive mesentery.
ect.,	. . . .	ectoderm.
end.,	. . . .	endoderm.
end. m.,	. . .	endodermal muscle.
end. sph. m.,	.	endodermal sphincter muscle.
f. mest.	. . .	mesentery of fourth cycle.
gr.,	. . . .	granular bodies in mesoglœa.
mes.,	. . . .	mesoglœa.
mes. sph. m.,	.	mesoglœal sphincter muscle.
mar. sphr.,	. .	marginal spherule.
mest. fil.,	. .	mesenterial filament.
par.,	. . . .	parapet.
p. b. m.,.	. .	parito basilar muscle.
œs.,	. . . .	œsophagus.
œs. gr.,	. . .	œsophageal groove.
ov.,	. . . .	ovaries.
p. mest.,	. . .	primary mesentery.
s. mest.	. . .	secondary mesentery.
t. mest.,	. . .	tertiary mesentery.
t.,	. . . . .	tentacle.

Fɪɢ.

1. *Phellia Sollasi.* Transverse section of half the column at the lower end of the œsophagus.

   [Through an oversight on the part of the artist, a tertiary mesentery has been omitted in fig. 1; it should have been inserted in the space between the two pairs of lateral primary mesenteries.]

2. *Phellia Sollasi.* Vertical section through the upper part of the column-wall and tentacles, showing the mesoglœal sphincter.

3. *Phellia Sollasi.* Lower part of section 2 enlarged, showing granular bodies in the mesoglœa.

4. *Actinia equina.* Vertical section through the margin of the disc, showing a marginal spherule and the endodermal sphincter.

LXXI.

ON THE OCCURRENCE OF ANATASE (XANTHITANE?) AND BROOKITE IN THE QUARTZITES OF SHANKILL. By PROFESSOR J. P. O'REILLY, C.E., Royal College of Science, Dublin. (PLATE XXV.)

THE outcrop of Cambrian strata, with accompanying quartzites, which forms the mass of Carrickgollaghan, the most northerly outcrop of this formation in the vicinity of Dublin, extends in a N.E./S.W. direction from Phrompstown in the S.W., to quite near the village of Shanganagh in the N.E., and is represented on the Geological Survey Map No. 121 with a total length of very nearly two miles in the direction mentioned, and a greatest breadth of about ¼th mile at a point lying about ⅓rd of the total length from its S.E. extremity.

Along the south-eastern margin is shown on the map an outcrop of quartzite; and a mountain road runs along it, from where it meets the Old Connaught-road at Shankill Castle, to where the formation terminates in the S.W.

The characteristics of the formation are given in the explanatory memoir to the sheets 121 and 130 (1869), p. 23, wherein it is stated that the country included in the two sheets is divided into districts of which the first (a) is the "Carrickgollaghan District," which is thus described :—

"The quartz rock of Carrickgollaghan Hill occurs in the form of a narrow ridge striking N.E./S.W., one mile and a-half in length, with a maximum width of 250 yards. At the S.W. extremity, where it also attains the greatest elevation of 912 feet, light-greenish and grey sandy slates, like Cambrian rocks, show themselves in the ground on the northern side, and, taken together with the quartz rock, would point to the Cambrian as being the group to which these rocks most probably belong.

"Blue and black slates are seen on its southern side, the discerned dips on the latter being to the southward at 30°. A bed of greenish felspathic ash occurs in the black slates at the southern boundary of the quartz rock, which fact, together with their colour and character, would group them in the Lower Silurian, rather than with the Cambrian rocks of the district. At the distance of 250 yards N.W. of the summit of Carrickgollaghan, there occurs a thin band of grey quartz rock about $\frac{1}{4}$ mile long and 40 yards wide, having smooth greenish-grey slates at either side of it. This and the former quartz band appear to belong to a boss of Cambrian rock, which probably rises through the dark Silurian slates and schists."

At p. 14, in the general description of the ground, it is stated:—

" At Carrickgollaghan, a boss of Cambrian slates and quartz rock appear through the Silurian rocks within half a mile of the surface edge of the granite. This is the closest surface approximation of the Cambrian to the granite, the width of the Silurian band being elsewhere never less than two miles, one half of which is metamorphosed into mica schist."

It is further added :—

" The relations of the Silurian to the Cambrian are everywhere very obscure, and to the north of Roundwood are absolutely undeterminable."

At p. 9, under the heading "Formations or Rock Groups entering into the Structure of the District," is mentioned "quartzite or quartz rock." Of this rock it is stated :—

"Here and there throughout the Cambrian rocks, there occur great belts and groups of beds of quartz rock. This has generally some shade of brown or yellow, sometimes becoming reddish, sometimes almost white; when examined with a lens, it is seen to be made up of minute granules of quartz, bound together by a siliceous cement, into a smooth, almost compact stone, intensely hard, but rather brittle."

At p. 10 is the statement :—

" It is jointed in every direction both by large visible joints and smaller imperceptible ones, which cause it to break up into small angular fragments. The original bedding of the rock can hardly be discerned in it, and its stratification can only be determined by following its upper and under surfaces, and tracing

their junction with the slates and sandstones above and below. Some of the grit stones are so siliceous, and some of the quartz rocks become so granular, that it is not always easy to determine whether to call any individual mass of rock a siliceous grit or quartzite. The principal masses marked on the map are very decided in character, and have always been called quartz rock by every geologist who has examined them. They vary in thickness from twenty to several hundred feet."

The facility of approach afforded by the road from Shankill Castle, across the hill, already referred to, along with the excellent quality of the quartzite as a material for road-metal, has led to the opening up of quarries along the outcrop which borders this road; and in these quarries, may be examined, as well the rock, as the systems of jointing and fissuring to which it is subject. As might *a priori* be expected, certain directions of jointing dominate, and have already been noticed for this locality in a paper read by me before the Royal Irish Academy in 1889. ("On the Directions of the main Lines of Jointing observable in the Rocks about the Bay of Dublin, and their relations with adjacent Coast Lines," part iii., p. 245. See also *Proceedings* Royal Irish Academy, 2nd ser., vol. iv., Science.)

The more important jointings are further characterised by being filled to a greater or lesser extent with a silicate of iron and manganese, dark-brown to black in colour, and intimately associated with quartz crystals. The jointings thus marked may be referred to four principal directions :—

(No. 1.) N. 6° : 15′ W.—Corresponding to the coast line direction between Six-mile-point and Ballygannon (lower New-castle district).

(No. 2.) N. 37° : 34′ E.—Corresponding to the general direction of the S.E. edge of Carrickgollaghan Hill.

(No. 3.) N. 62° : 30′ W.—A well-marked system of jointing, according to which there had evidently been repeated movements, having given rise to breccia formation along the joints, with inter-position of the iron-manganese silicate already referred to. This direction corresponds very exactly with that of Glencullen Valley, in the part of it which traverses the granite formation.

(No. 4.) N. 70 : 47′ W.—Corresponds to the systems of jointing

which traverse Bray Head, also mentioned in the papers already referred to.

The quarry nearest to Shankill Castle (the entrance to which is from the road leading to Old Connaught) was being worked for road metal about ten years ago, and in the southern end of it, the quarrymen came on a joint filled with a soft yellowish earth, having a soapy feel, which they had not met with before, and which presented itself in such quantity that one of the men (Jos. Mills, of Shanganagh village) subsequently informed me that a ton of the earth might easily have been secured at the time. The sample which he brought me, at the time of the discovery was, owing to pressure of other business, put aside for future examination. This only took place last year, and meanwhile the quarry had been completely abandoned for years, so that no further traces of the joint, or of the contained earth could be found, and only an approximate direction of the joint in which it occurred could be determined.

This direction would (according to Mills' indication) be about N. 6°-7° E., and would correspond to a system of jointing which shows itself in the quartzites lying to the east of the Sutton Coast-guard Station (and quite under the Martello Tower) with marked frequency.

Circumstances having led me to examine the sample in question, I first "panned" a certain quantity of it, and was surprised to notice in the "tail" or heavy remaining residue, certain minerals, in a sufficiently crystallized state to allow of their further examination. Nearly the whole sample was therefore carefully panned, the heavy part separated, and this carefully classed according to size, and hand-picked, when necessary, under the lens. I was thus able to obtain a sufficient quantity of these crystals to allow of a determination of their characteristics being satisfactorily made. A large quantity of quartz crystals were separated out, more or less cariated and imperfect; along with these occurred crystals of a somewhat metallic lustre, presenting forms referable to the tetragonal system, being for the most part doubly terminated tetragonal pyramids, with oscillations of the upper and lower faces as shown in the plate (fig. 2). With these occurred, a mineral having also a submetallic lustre, a brown colour, a platy structure, and evidently of nearly the same density as the former.

After careful examination and measurement of the middle edges of the first-mentioned mineral it was set down as *anatase*. The density was determined, and gave a mean result of 3·587, which is distinctly lower than that of anatase proper, which is given in Zirkel's " Mineralogy," as 3·83 to 3·93.

It is to be remarked, however, that it was very difficult to obtain crystals so perfectly free from adhering parts and particles of quartz, as to allow of their being taken as perfectly pure. Hence, however careful the hand-picking, some adhering quartz remained on the crystals examined for density. This, of course, operated to lower " pro tanto " the density below the normal figure. In order to clear up this apparent discrepancy, a sufficient sample of hand-picked crystals was entrusted to Mr. W. L. Warren, F. C. S. for careful analysis. His report gave the composition of the crystals (No. 1) as below. Thinking that the alumina therein shown might have proceeded from minerals which had either accompanied the sample, or were adherent to the crystals as hand-picked, a further portion was very carefully hand-picked under the lens and this further sample entrusted by me to Mr. Warren, who reported as composition the analysis (No. 2) as below.

	(No. 1).			(No. 2).
	Percentage.			Percentage.
SiO_2,	3·30,			3·07
Al_2O_3,	12·86,			13·02
FeO,	15·20,			10·40
Fe_2O_3,	1·05,			6·01
CaO,	2·29,			2·16
MgO,	4·42,			4·42
MnO,	traces			traces
TiO_2,	60·72,			60·81
(K_2O and Na_2O)	0·06,			0·12
Combined Water,	0·06,			—
	99·96			100·01

The main difference from one sample to the other was in the iron ; and it was concluded that the alumina found was present as an essential constituent of the mineral.

Assuming this for the present, it is evident that the composition shown is different from that of any known *Silico-titanate*, such as mentioned by Dana in his " System of Mineralogy " (edit. of 1892), and, if confirmed, may represent a new mineral, or mineral variety,

that is, an anatase in which a certain amount of TiO_2 is replaced by alumina, as it is frequently by SiO_2.

Keilhauite bears to it a resemblance only in so far as it is a titano-silicate of CaO, Al_2O_3, Fe_2O_3, and Y_2O_3 the density being 3·52 to 3·77, but the crystalline form (monoclinic) and the other characteristics differentiate it markedly. It suggested, however, that the alumina might be accompanied by some of the rarer earths. An analysis was undertaken for the determination of the presence of such rare earths, but the results were negative. In the same edition of Dana, mention is made, on p. 716, of a mineral called *Xanthitane*, of which the following details are given by Eakins whose analysis thereof is also given. He considers it as an alteration product after *Titanite*. He gives the colour as light yellow, and says it was mixed with impurities to an undetermined extent. He calls it a clay containing titanium in place of silicon, and states that the analysis given is of a material obtained from Green River, Henderson Co., N. C. (U.S.A.). It is interesting to place his analysis side by side with that of the Shankill anatase by Mr. Warren.

	Xanthitane.	Shankill Anatase.
	Percentage.	Percentage.
SiO_2,	1·76,	3·30
Al_2O_3,	17·59,	12·86
FeO,	—	15·20
Fe_2O_3,	4·46,	1·05
CaO,	0·90,	2·29
MgO,	traces,	4·42
MnO,	—	traces
TiO_2,	61·54,	60·72
Ph_2O_5,	4·17,	—
H_2O,	9·92,	0·06
(K_2O and Na_2O),	—	0·06
	100·34	99·96

There is an evident resemblance between these two analyses, so much so, that it might be presumed that the yellow earth analysed by Eakins from Green River, Henderson Co., U.S., was most probably the product of the decomposition of an anatase mass having originally had the same composition as that of the Shankill specimen or nearly so.

Subsequently to the analysis of the crystals, Mr. Warren made

an analysis of the yellow earth as originally found, but freed from the larger parts. The following was the results reported by him, showing the presence of the TiO_2 in notable quantities in the fine part of the clay and to a certain extent accounting for the colour of it :—

	Percentage.
SiO_2, ...	44·40
Fe_2O_3, ...	6·75
FeO, ...	—
Al_2O_3, ...	35·45
CaO, ...	0·65
MgO, ...	0·99
Na_2O, ...	0·10
TiO_2, ...	6·22
Combined H_2O, ...	5·46
	100·02

A sample of the same clay was also submitted to Mr. H. Ramage, assistant chemist in the Royal College of Science, Dublin, for examination by the spectrographic method so remarkably applied by him in collaboration with Professor W. H. Hartley, F.R.S., to the determination of the presence of certain of the rare elements in minerals and ores, as detailed in their Paper published by the Chemical Society (see *Transactions*, 1897, p. 533 ; and *Proceedings*, Royal Society, 1896, 60, p. 35 ; 1897, 60, p. 393).

Mr. Ramage's results were as follows :—

In the precipitate containing the iron alumina, &c., were found iron aluminium ; copper ; nickel ; silver ; gallium ; calcium ; lead ; chromium ; (traces of) ; sodium ; and potassium. In the residue containing the alkalies, were found—sodium ; potassium ; rubidium ; caesium ; lithium ; calcium ; strontium ; copper ; iron (traces of) ; manganese.[1]

Along with the anatase minerals occurred small crystals of brookite (Pl. XXV., fig. 1), presenting the usual characteristics of that mineral, and forming light-brown plates, striated, and of a sub-metallic lustre ; in some cases showing sufficiently well-defined crystalline forms to allow of these being determined ; moreover,

---

[1] Silica and titanic acid were not looked for, but only those bases present in small quantities. By the ordinary method of analysis, gallium as sesquioxide would be precipitated along with the alumina.

the density was found to be 3·928 (mean), which quite agrees with the mean value of the densities indicated for that mineral, viz. 3·8 to 4·1.

There is room for considering the probable origin of these titanic acid minerals as they occur in the Shankill quarries, and the clays therein found. It is to be borne in mind that minute crystals of rutile have been shown by microscopic examination to be present in most slate rocks, and, furthermore, that the presence of titanic acid has been proved by chemical analysis of various samples of the rocks of Bray Head, mostly as traces. It might therefore be assumed that the quartzites so characteristic of Bray Head and Carrickgollaghan would also show traces of that mineral, and its general diffusion through the whole of the strata of the "Carrickgollaghan district," in minute quantities only determinable by very careful analysis. However, in the case of the Shankill quartzites there is evidence of thermal action in the abundant deposits of a ferro-manganese silicate along the main lines of fracture, as already mentioned, and in the cariated character of the quartzites in immediate contact with these ferro-manganese silicates, as well as the altered texture of these quartzites, which are so friable and "rotten" as to be useless for the purposes of road-metal. The examination of these particular quartzites in thin section, while showing the granular texture of the rock, points to a certain alteration in the structure of the quartz, such that it assumes the appearance of calcedony under polarised light, not to the point of showing the aggregation cross on rotation, but an extinction seemingly due to the development of a fibrous structure which bears a certain relation to that of calcedony. Another character of certain of the quartzites of Bray Head, points in this direction, that is, a relatively low density. Thus a specimen of quartzite from Windgate (Bray Head) analysed by Mr. Shegog (formerly Assistant Chemist in the Royal College of Science, Dublin), and marked by me No. 23, BH, gave a density, as determined by him, of 2·605, which corresponds well with that of calcedony, as given by Dana, viz. 2·6–2·64, that of quartz being given by the same author as 2·653–2·654. It is right to add that the quartzite in question only contained 90·63 per cent. of SiO_2, but the other constituents indicated in the analysis might, with reason, be looked as tending

rather to raise the value of the density than to reduce it. The analysis is as follows :—

	Percentage.
SiO_2, ...	90·63
Al_2O_3, ...	1·79
Fe_2O_3, ...	0·34
CaO, ...	4·45
MgO, ...	0·14
LiO_2, Na_2O and K_2O } calculated as Na_2O, }	2·51
	99·86

This calcedony character of the quartz may reasonably be taken as pointing to extensive thermal action along the main lines of fracture, and would receive a certain amount of illustration from the similar phenomena presented by certain quartzite beds which occur in the Carboniferous formation of St. Etienne (Loire), and which I was enabled to examine and have explained to me by Monsieur de Grand d'Eury during an excursion to that mining district with the French Association for the advancement of science, which took place last August. In this case the alteration of the rock into calcedony is manifest and clear in all its stages, and as I was informed by M. de Grand d'Eury, accompanied by the concentration of titanic acid in certain zones and the consequent presence of the minerals therein usually representing that acid.

It is worthy of note that the district of St. Etienne possesses several gaseous mineral springs of noted quality in the country, which may be taken as the residual efforts of the forces which have left such marked results in the alterations and derangements of the strata so well studied by the eminent geologist already mentioned.

It would be desirable that the whole of the quartzites of the Co. Wicklow and of the neighbourhood of Dublin be examined carefully and comparatively from the point of view of constitution and the alterations which they have undergone at their contacts with other rocks in different localities of the districts mentioned.

EXPLANATION OF PLATE XXV.

Figs.

1. Brookite, from Quartzites, Shankill, Co. Dublin ; forms presented : $t = 2P\breve{\infty}$; $y = \frac{1}{2} P \bar{\infty}$; $e = P\breve{2}$; $l = P\bar{2}$.

2. Anatase, from Quartzites, Shankill, Co. Dublin.

LXXII.

ON SOME MINUTE ORGANISMS FOUND IN THE SURFACE-WATER OF DUBLIN AND KILLINEY BAYS. By HENRY H. DIXON, D.Sc.; and J. JOLY, D.Sc., F.R.S., Hon. Sec. R.D.S.

(Plates XXVI. and XXVII.)

Last summer we started tow-netting in Killiney Bay in the hopes of finding coccoliths, and adding something to our knowledge of these peculiar bodies.

Our first observations were made by skimming the surface-water with a funnel-shaped metal surface-dredge. This consisted of a truncated cone made of tinned iron. The wide end of the cone, which was trailed foremost through the water, was covered with a piece of brass-wire gauze, having 50 meshes to the linear inch. The narrow end was closed by a much finer piece of gauze, having 350 meshes to the inch. This latter piece of gauze was carried on the end of a short brass tube, which fitted into the truncated end of the conical dredge with a bayonet joint. The whole was floated by means of two wooden wings, extending from the sides of the cone.

In use, a constant stream of water was kept up through the funnel by means of the motion of the boat from which it was trailed, and when it was raised for examination, the water contained in the funnel was allowed to run out through the fine gauze. In this way, none of the smaller organisms, which had got into the funnel, escaped through the coarse gauze; when all the water had run through the gauze, the brass tube carrying it was taken out, and the material caught on it was washed off and bottled. In this manner, very concentrated samples of the smaller surface-organisms were obtained. The larger, such as jelly-fish, &c., were excluded by the coarser gauze in front.

Although this apparatus allows the very minute bodies suspended in the surface-water to escape, it affords beautiful samples of Foraminifera, Diatoms, Crustacea, Infusoria, Peridineæ, &c. ; and we were rewarded by soon finding specimens of the bodies we were looking for—the coccoliths. These occurred, not free ; for they are so minute as to easily pass through the meshes of the finer gauze, nor yet aggregated in coccospheres, as Wallich[1] described having found them in shoal-water off the south coast of England, but implanted on an amœboid protozoan, resembling a Difflugia in appearance.

This protozoan occurs in great quantities in the surface-water off the coast of Dublin and Killiney Bays. It is urn-shaped (fig. 8), and narrows suddenly to the aperture which is surrounded with a collar of hyaline siliceous material. Lobose pseudopodia are extruded through this collar in life, and its internal edge is ornamented by a circlet of minute teeth, standing up from it obliquely. The urn-shaped covering of the organism is covered with thin flat grains of sand fitted into each other with nicety. Among these grains, fragments of sponge spicules may occasionally be seen, and, besides these, an odd coccolith was often observed implanted in the test. In fact, we estimated that about 25 per cent. of these Difflugia possess one or two coccoliths.

Fig. 8 shows a coccolith, *in situ*, on the Difflugia. The coccolith frequently occupies a position on the shoulder of the protozoan, or it may be closer to the collar. More rarely it is found on the converging conical end of the test.

This find encouraged us to pursue our search. For it appeared probable that the coccoliths had been acquired by the protozoan in the same manner as the grains of sand, and that, like the latter, they were floating free, suspended in the sea-water. If this surmise as to the relations of the two organisms was correct, it must follow that examination of the most minute solid constituents of the sea-water would reveal the presence of free coccoliths in considerable numbers.

To test this question, two litres of sea-water were allowed to stand twenty-four hours in a tall, narrow jar ; the upper portion was then siphoned off, leaving about 200 c.cs. of the lower

---

[1] Ann. and Mag. of Nat. Hist., 1868.

portion. This was treated in a centrifugal apparatus. By this means the water was cleared of all turbidity, and its solid contents were thrown to the bottom of the test tubes of the centrifuge, in the form of a compact mat of whitish gray material.

Examination of this material showed at once that coccoliths abounded in the free state in the sea-water. Their numbers, indeed, exceeded all anticipation, for there were about 100 on each slide prepared from the precipitates which formed in the centrifuge. An estimate of the actual number present in the sea is equally astonishing. A sample of water taken 3 miles off the coast, on a calm day, afforded 200 coccoliths in each cubic centimetre. The estimate was made by permitting the solid matter of a large volume of water to settle. The clear upper fluid was then siphoned off, and the remainder with the solid contents of the whole was vigorously shaken up. The number of coccoliths in a drop of this latter was then estimated by means of a divided stage (such as is used in counting blood-corpuscles). From this the number present in the original volume is obtained. Several closely agreeing estimates of the number present in the same sample gave the above-mentioned remarkable result.

The centrifuge was an efficient way of getting large numbers of coccoliths, but all the solid matter suspended in the water was so closely compacted by its action that a clear view of the contained organisms was often difficult to obtain from this material. Later on, we found that the simplest manner of obtaining these bodies was straining large quantities of sea-water through fine silk; a procedure which, in the anticipation of finding but very few specimens, we did not at first adopt. The silk should be stretched as a diaphragm across the lower end of a wide glass tube (the chimney of an argand-burner answers well for this purpose), and while the latter is held in a vertical position, sea-water is poured in above. After many gallons have passed through, the silk is removed, and washed in a small quantity of water, and the washed-off precipitate bottled. We found this method more satisfactory than towing the strainer in the water. In the latter case a backwash, which may lead to the loss of much of the material gathered, is always liable to occur.

These methods supplied us amply with material to study the form and manner of occurrence of the coccoliths. These

problematical bodies consist of two very thin elliptical valves, about
·015 mm. in length. The valves are saucer-shaped; and one
which is slightly larger than the other partially includes the
smaller. The central portion of the outer valve is re-entrant, so
as to form a short, funnel-shaped collar, connecting it with the
inner valve. The bottom of this funnel-shaped depression in the
convex surface of the outer valve is an elliptical plate, which also

a

d

b

e

c

f
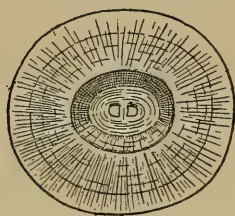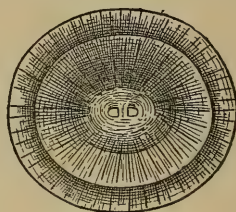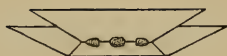
(*a*) Coccolith seen from above, larger valve
    turned upwards.
(*b*) Viewed obliquely, larger valve upper-
    most.
(*c*) Seen in longitudinal section, smaller
    valve above.

(*d*) Seen from above, smaller valve upper-
    most.
(*e*) Seen obliquely, smaller valve turned
    upwards.
(*f*) Seen in profile, smaller valve above.

forms the bottom of the smaller saucer-shaped valve. This plate
is thicker than the rest of the valve, and is perforated. The
perforation may be single, when it is an elongated oval (the length
of the oval lying longitudinally in the coccolith), or it may be
double when there are two D-shaped holes placed back to back, as
if the oval perforation had been converted into two by the deposi-
tion of a bridge of material across its centre. A reference to the

foregoing figures will explain the form of the coccolith. It will be noticed that the connecting stalk between the two valves is much shorter than that given in the figures of Bütschli, and that it is scarcely correct to describe these bodies as resembling a shirt-stud in shape.[1]

The coccoliths dissolve quickly in dilute hydrochloric acid, and are partially and much more slowly attacked by strong caustic potash. The latter reagent does not appear to be able to completely dissolve the central parts, more especially of the small valve, or, at least, cannot do so with any celerity. The absence of the appearance of free gas upon attack with acids hardly negatives the generally accepted view that these bodies are calcareous. In all these tests we have frequently had characteristic Diatoms present in the same field; and whereas the siliceous valves of the latter were unaltered by the acid, the coccoliths were quickly dissolved. In the application of the caustic potash test, diatom-valves were also present, and these showed complete resistance to the caustic alkali.

The appearance of a coccolith in polarised light is characteristic. Between crossed nicols, the thin flange of the large valve appears inactive; the entire inner ellipse, on the other hand, exhibits a dark cross, the arms, in some cases, revealing a certain amount of spiral bending. A somewhat complex crystalline structure is thus suggested.

That there is some organic matter present between the valves appears suggested by the granular appearance often presented in the annular chamber, embracing the central connexion, and also by the fact that, upon solution in dilute acid, just such a ring of granular particles is thrown down, and alone remains to mark the spot where the coccolith had been. This ring assumes a tawny yellow or brownish colour when acted upon by iodine. Or, again, if the coccolith be treated with strong *liquor iodi*, the valves dissolve, and this ring remains as a dark granular ellipse.

From these observations, it would appear that a ring of (residual?) protoplasmic matter surrounds the central connexion. In many specimens of free coccoliths we have seen a slimy, possibly proteid, mass depending from the smaller valve, or enveloping the

---

[1] Bütschli: Protozoa. Plate I. Wyville Thomson. The Depths of the Sea, p. 413.

entire concave surface of the coccolith (fig. 2). But in this we never were able to detect any marked movement, nor other definite sign of life. Neither were we able to observe nucleus nor any evident chromatophores.

Although the free coccoliths are so abundant we were able to find but few coccospheres. After many prolonged searches we have only come across a half-dozen or so. The coccoliths aggregated on these presented, as a rule, a much less battered appearance than those free in the water—a fact which is suggestive that the coccospheres are the source of the coccoliths.

The observation of Wallich, that a membranous covering envelops the coccosphere,[1] seemed to us supported by the appearance of these bodies. The whole contour is singularly spherical, and such that the component coccoliths appear as if fitted together, at least partially, by pressure from without.

Upon treatment with dilute acids the coccospheres dissolved, and a globule of pale brown or yellowish proteid matter remained behind, agreeing with the observations of Wyville Thomson[2] and others.

Our observations up to the present are hardly such as to give us any advantage over previous observers in forming an opinion as to what may be the nature of coccoliths and coccospheres. Two suggestions present themselves. The first, the already well-known one, that the primary body is a small and abundant alga, which secretes upon its surface the shield-like coccoliths. These, upon the death of the coccosphere, are liberated. As will be seen further on, other spherical bodies of almost the same dimensions are present in the water, and these secrete each characteristic forms of investing shields. A class of minute algæ (?) should, if this suggestion prove true, be recognised which might embrace coccospheres and rhabdospheres, as well as two organisms to be described later.

Or, again, it may transpire that the coccosphere is a reproductive stage in the life-history of coccoliths (these latter being independent individuals). The coccosphere might then be regarded as somewhat homologous to the plasmodium of the Myxomycetes, formed by the adhesion of a number of independent organisms, or it may prove rather to represent an auxospore, such as is found in

---

[1] Ann. and Mag. of Nat. History, 1860.   [2] *Loc. cit.*

the Diatoms, differing, however, from them in the fact of its giving rise to a number of individuals.

In order to ascertain if coccoliths are widely distributed around our coasts, we examined specimens of the solid matter found in the sea-water, with a positive result, off the following places :— Sligo, Slyne Head, Tralee, Smerwick Harbour, Dingle Bay, Valencia, Waterville, Kenmare River, Dublin, and Weymouth. We did not find any in water gathered in Loch Inver nor Port Stuart.[1]

Again, the coccoliths are present at different seasons of the year. This fact we have ascertained in part by fresh specimens, and in part by specimens which have settled down with other solid matter off algæ, gathered in different localities and preserved in spirit :—

Spring, 1894, . Smerwick Harbour, Dingle Bay. (Spirit specimens.)

Summer, 1896, . Kenmare River. (Spirit specimens.)

Summer, 1897, . Dublin Bay, Killiney Bay, Valencia, Sligo. (Spirit and Fresh.)

Winter, '97–'98,. Killiney Bay, Waterville, Dingle Bay, Kenmare River, Slyne Head, Weymouth. (Fresh.)

A coccosphere was found in water taken at Weymouth in the winter.

The coccoliths obtained in Killiney Bay in winter seemed to be more battered than those caught at the same locality in summer.

Coccoliths have been frequently described as occurring in various geological deposits.[2] We have found them in chalk from Newhaven, and also in commercial whiting. The latter is almost exclusively formed of these peculiar bodies. In both these, however, other organisms are to be seen resembling coccoliths in their

---

[1] Since the above was written we have found several coccoliths on the tests of Difflugia, but none free, in samples of sea-water from Portrush.

[2] Cretaceous, upper greensand immediately above the Gault ; coccoliths and rhab-doliths were found in the Hearthstone, Bletchworth, Surrey. W. M. Holmes : Proc. and Trans. Croydon. Micr. and Nat. Hist. Club, 1892-93, pp. 17-20.

Coccoliths are also said to be found in Palæozoic rocks. Nicholson and Lydekker, Palæontology, vol. ii.

general appearance, but sometimes rather larger or smaller, and differing from them slightly in their structure. Sometimes they are quite circular.

In specimens of Severn mud (obtained in excavating the tunnel), and also in mud obtained from borings in the bed of the Liffey, we have found examples exactly resembling recent coccoliths. Another peculiar locality, in which we discovered coccoliths, was the muds used to bind together the Papyrus MSS. in making the mummy-cases which were found by Mr. Flinders Petrie at Fayyum.

With the coccoliths we obtained a large number of minute organisms. One of the most abundant was the Difflugia-like organism on which our first coccolith was found. Although so abundant, we have not yet succeeded in identifying it with any previously described protozoan. It resembles the genus Difflugia in having lobose pseudopodia, and being enclosed in an urceolate test indurated with particles of sand. But the marine habitat and the very definite annular collar have not before been observed in this genus, so far as we are aware. It is true that Pritchard[1] says that Bailey obtained a specimen from a depth of 2750 fathoms, which he called *Difflugia marina.* But its marine habitat led the discoverer to doubt its being a Difflugia. In any case, it is described as having a chitinous test divided into quadrilateral areas. The empty test almost exactly resembles that figured by Claparède and Lachmann[2] as belonging to *Tintinnus ventricosus;* but of course the structure of its inmate makes it impossible to classify it with the ciliate Infusoria. We would provisionally suggest the name *Difflugia thalassia.* We may add, as further connecting it with the genus Difflugia, that we have found several specimens united in pairs by the foramina in conjugation exactly as Leidy[2] figures this process in Difflugia (fig. 9).

Fig. 5 represents an organism of which we found two or three specimens. With a low objective it resembled the antenna of an insect in general appearance, being jointed, the joints of which it was composed diminishing uniformly from the greatest to the smallest. On closer examination it was found that the larger joints resembled

---

[1] Infusoria, p. 554.

[2] Études sur les Rhizopodes et les Infusoires.

Difflugia in form and size. They were also incrusted with minute granules of transparent sand. We figure it here, as it may possibly be found to be a stage in the reproduction of Difflugia. If this turn out to be correct, it is a catena of Difflugia similar to what is well known as occurring in *Ceratium tripos*. Of course this is mere speculation, as we have not yet had opportunity of seeing the further development of this unknown structure, if further development it has.

Besides the tests or loricæ of the Difflugia, the tests of several other protozoa are found in the surface-water of the locality. The most numerous of these was, perhaps, *Tintinnus campanula*, a beautiful bell-shaped infusorian. The test, like that of Difflugia, is inlaid with particles of sand. These are, as a rule, much thinner than those on Difflugia. We never found a coccolith in the test of this infusorian. When found, the test was most usually empty ; however, on several occasions, we found it tenanted by the living infusorian, which exhibited all the characteristic energetic motions of the genus.

Again very frequent in occurrence were other small tests resembling that of Difflugia in shape, except that they were not constricted at the aperture, and had no distinct collar. There were at least two species of these, one tapering almost uniformly from the widest place (fig. 7), and the other slightly constricted above the widest place, and then slightly expanding again, to finally taper to a delicate point. Both these tests were occasionally found inhabited by a heterotrichan infusorian. The latter seems identical with *Tintinnus annulatus*, as described by Claparède and Lachmann. The former (fig. 7) we propose to call *Tintinnus conicus*.

Of the Foraminifera we found many examples, notably specimens which appear to be *Rotalia veneta*, *Globigerina bulloides*, Milliola, sp., *Textularia picta*.

The Diatoms were very varied; among the more interesting were the following :—*Actinocyclus undulatus*, *Actinoptychus senarius*, *Coscinodiscus radiatus*, *Melosira nummuloides*, Arachnodiscus, sp., Pleurosigma, several sp., Chætoceras, 2 sp.

Another group, which was very numerously represented in the surface-water, was the Peridineæ. *Ceratium tripos* vied with *Difflugia thalassia* to outnumber it in the plankton of the locality. Besides *C. tripos* (fig. 11) and its variety *macroceras*, *C. fusca*, *C.*

biceps (fig. 12), *C. fusus* (fig. 13), *C. divergens* (fig. 16), (both in the motile and spore-producing stages), *C. michaelis*, and two species of Dinophysis, apparently *D. norvegica* and *D. acuminata* (fig. 14). To these may be added *Prorocentrum micans* (fig. 17). Of the Radiolaria we found only *Dictyocha trifenestra* (fig. 15).

In addition to the forms just described, and which can be more or less easily referred to known groups and genera, we came across, in this investigation, several organisms which, so far as we know, have not been described. Among these were two or three specimens of a minute sphere (fig. 1), somewhat larger than a coccosphere (*i.e.* about ·05 mm. in diameter). It consists of a mass of protoplasm, carrying in it yellow-brown colouring matter, and covered by a delicate pellicle, in which are supported a number of ⊤-shaped spicules. On treatment with dilute hydrochloric acid, the pellicle remains, but the spicules dissolve. The spicules seem each to arise from an oval plate carried in the pellicle. From the peculiar spicules we may call this an "Echinosphere."

About the same size as the Echinospheres, and occurring also in the same sporadic manner, was another spherical body (fig. 3). In this the protoplasmic basis was covered over with oval scales of calcium carbonate. A short conical point rose from the centre of each scale, and projected from the surface of the sphere. From the peltate scales, we term this a "Peltasphere." This body we also found in surface-water gathered off Valencia Island. Within the "Peltasphere," one or more greenish granules could be observed.

In much greater abundance than the Echinospheres, or Peltaspheres, were two cyst-like structures, resembling Ehrenberg's Xanthidia and Pyxidicula. Ehrenberg described these from the chalk, and, so far as we know, they are not described as being recent. The forms resembling Pyxidicula are spherical shells of a chitinous substance, golden brown in colour. Their surface is finely punctate. They are about ·084 mm. in diameter (fig. 10). Sometimes they are complete, and contain coarsely granular protoplasm within them, which appears to have an inner and more delicate pellicle covering it inside the chitinous shell, sometimes they are irregularly ruptured, or opened with a circular or tri-radiate slit. These Pyxidicula seem to us to be, in all probability, encysted protozoa.

The Xanthidia-forms are more definite. We have only observed empty cysts. These are spherical chitinous shells from which arise a number of short, stout, tubular spines, each apparently broken irregularly at the apex. The Xanthidia of the chalk have been described as the zygospores of Desmids. The occurrence of pelagic organisms of this form removes the necessity of the unwelcome dilemma, of assuming a partial freshwater origin of the chalk (!), or of presupposing marine Desmids.[1]

In conclusion of this, which must, at best, be only a preliminary sketch, we wish to express our thanks to Dr. E. Perceval Wright for calling our attention to a great mass of literature on this matter, especially Dr. Wallich's Papers, dealing with the Rhizopoda, and also for giving us the opportunity of consulting many of the works needed in his own resourceful library.

---

[1] Wallich, "North Atlantic Sea-Bed," 1862, states that he detected Xanthidia in the stomachs of Salpæ in the Indian and Mid Atlantic Oceans in 1851.

[Explanation of Plates.

EXPLANATION OF PLATES.

—

Plate XXVI.

Figs.

1. Echinosphere. × 580.

2. Coccolith with proteid slime attached. × 1000.

3. Peltasphere. × 580.

4. Xanthidia. × 420.

5. Chain of urceolate chambers, each of which resembles an individual *Difflugia thalassia*. × 160.

6. Test of *Difflugia thalassia* seen obliquely from below, showing the siliceous collar and delicate teeth. × 310.

7. Test of *Tintinnus conicus*. × 580.

8. *Difflugia thalassia* with pseudopodia extended. On the test is seen a coccolith among the grains of sand. × 310.

9. Two individuals of *Difflugia thalassia* in conjugation. × 310.

10. Various forms of spherical tests resembling Pyxidicula. × 310.

—

Plate XXVII.

11. *Ceratium tripos.* × 310.

12. *Ceratium biceps.* × 310.

13. *Ceratium fusus.* × 310.

14. *Dinophysis acuminata.* × 580.

15. *Dictyocha trifenestra.* × 420.

16. *Ceratium divergens.* × 310.

17. *Prorocentrum micans.* × 580.

LXXIII.

AN IMPROVED FORM OF HYDROMETER BY WHICH THE SPECIFIC GRAVITY OF LIQUIDS MAY BE ACCURATELY DETERMINED AT ANY TEMPERATURE. By the REV. H. O'TOOLE, of Blackrock College, County of Dublin.

In numerous manufacturing processes, in commercial transactions, and in scientific investigations, an accurate knowledge of the specific gravity of the liquids used is a matter of the highest importance. This knowledge affords, in many cases, the readiest means of identifying a given liquid or of detecting in it the presence of a foreign substance. More important still it enables us in the simplest manner, to estimate the value of alcoholic, saccharine, acid, or other similar solutions: for the density of such solutions depends on the amount of alcohol, sugar, acid, &c., which they contain.

It is not therefore to be wondered at that so many methods of determining specific gravity should have been proposed. Here, it will not be necessary to speak of methods requiring the use of sensitive balances or other delicate apparatus. These may be useful or necessary for special purposes, but are not of general application. In practice some form of hydrometer is almost invariably used. The common hydrometer consists of a long thin stem with a weighted bulb at one end ; when placed in a liquid it floats vertically, and the distance to which it sinks, as shown by a scale on or inside the stem, indicates the density of the liquid.

The simplicity of this instrument is its principal recommendation, but, unfortunately, what is gained in simplicity is lost in accuracy. The indications given are only to a certain extent approximate, as a little consideration will show. The scale, when most carefully made, is obtained by marking on the stem the points to which it sinks when immersed in liquids of known densities, and the intermediate densities are then marked off by some method of approximation. As the calibration is made for some particular temperature the indications will be incorrect if the

liquids are at any other temperature. This is a great draw-back; for, in practice, it is very troublesome to bring liquids to a given temperature, especially if they are hotter than the standard and have to be cooled.

Perhaps the most serious, because altogether unavoidable, source of error is that due to capillarity or surface tension. All estimations of density are based on the supposition that the distance to which the hydrometer sinks is due to its weight alone; but this is not quite correct. The reading of the instrument is also affected, and to a very appreciable extent, by the capillary attraction of the liquid. As this capillary attraction is generally different for different liquids, it follows that a hydrometer will necessarily indicate different densities when placed in liquids having the same density, but differing in capillarity.

From all this it is apparent that specific gravities determined by the common hydrometer must, in the majority of cases, be considered as little better than fair approximations.

Nicholson's hydrometer, though it has no scale, is still adversely affected by capillarity. Indeed, this source of error was pointed out by Nicholson himself: moreover, the instrument loses nearly all its value from the fact that its weight must be known, and as this weight is liable to change through use, a delicate balance must be at hand to determine it when necessary.

The hydrometer (see figure) which the writer proposes is free from the above-mentioned defects. It has no arbitrary scale; its weight need not be known; the effect of capillarity is totally eliminated, and it may be used for any temperature. The illustration shows clearly the shape of the instrument. The method of using it is very simple. It is immersed in any liquid, and weights put on the dish at top until it sinks to a marked point between the second and third bulbs; additional weights are now put on until it sinks to

a second marked point between the third bulb and the dish. These additional weights are evidently, according to the well-known law of Archimedes, the weight of a volume of the liquid equal to the bulb between the two points. In this way the weights of the same volume—the volume of the bulb—of any two liquids may be determined with extreme accuracy, and their relative densities may easily be calculated. The fact of having two standard points completely eliminates the effect of surface tension, so fatal to the accuracy of all other forms of hydrometer. It has a great advantage in that it requires only two spindles of convenient size for all liquids from the heaviest to the lightest: Twaddell's form of the common hydrometer requires six spindles for heavy liquids alone, and as many others would be required for light ones.

The proposed hydrometer should prove useful in junior experimental classes; it is inexpensive; a beginner can obtain with it the most accurate results, and, above all, the accuracy of the result will depend entirely on the worker.

INDEX

TO VOLUME VIII.

END OF VOL. VIII.

Plate XX.

PLAN OF DRILL

SPIRAL NEBULA
IN
CANES VENATICI.

Plate XXII.

Proc. R.D.S., N.S., Vol. VIII.

Co

Fe

Plate XVIII.
Proc. R.D.S. N.S. Vol.VIII.

Mn

Plate XXIV.

1

2

3

ACTINIARIA.

× 60

× 100

BROOKITE (1.)   ANATASE (2.)

Plate XXVI.

Plate XXVII.

11

12

13.

14

15

16

17

SCIENTIFIC PUBLICATIONS

OF THE

ROYAL DUBLIN SOCIETY.

TRANSACTIONS:

Quarto, Published in Parts, stitched.

CONTENTS OF VOLUME I. (New Series).

CONTENTS OF VOLUME II. (NEW SERIES).

CONTENTS OF VOLUME III. (NEW SERIES).

CONTENTS OF VOLUME IV. (New Series).

(**5**)

PART.

CONTENTS OF VOLUME V. (NEW SERIES).

CONTENTS OF VOLUME VI (New Series).

PART.

13.—Of Atmospheres upon Planets and Satellites. By G. Johnstone Stoney, M.A., D.SC., F.R.S., F.R.A.S., Vice-President of the Physical Society, &c. (November, 1897.)

14.—Jamaican Actiniaria. Part I.—Zoantheæ. By J. E. Duerden, ASSOC. R.C.SC. (Lond.), Curator of the Museum of the Institute of Jamaica. Plates XVII. A, XVIII. A, XIX., XX. (April, 1898.)

15.—Radiation Phenomena in a Strong Magnetic Field. By Thomas Preston, M.A., F.R.U.I. Plate XXI. (April, 1898.)

16.—The Actiniaria of Torres Straits. By Alfred C. Haddon, M.A., D.SC., Professor of Zoology, Royal College of Science, Dublin. Plates XXII. to XXXII. (August, 1898.) [*Title-page, Contents, and Index to Volume VI., Series II.*]

PROCEEDINGS:

Octavo, Published in Parts, stitched.

VOLUMES I. to VIII. (NEW SERIES) COMPLETE (1877 to 1898.)

LIST

SOCIETIES AND INSTITUTIONS

WITH WHICH

THE ROYAL DUBLIN SOCIETY EXCHANGES PUBLICATIONS.

GREAT BRITAIN AND IRELAND.

England and **Wales.**

Bath.
International Journal of Microscopy and Natural Science.

Birmingham.
Central Free Libraries.
Mason University College.

Bootle.
Free Library.

Bradford.
Public Free Library.

Camborne.
Mining Association and Institute of Cornwall.

Cambridge.
Philosophical Society.
University Library.

Cardiff.
Naturalists' Society.

Cockburnspath.
Berwickshire Naturalists' Field Club.

England and **Wales**—*continued.*

Darlington.

　Edward Pease Public Library.

Dudley.

　Dudley and Midland Geological and Scientific Society.

Falmouth.

　Royal Cornwall Polytechnic Society.

Gateshead.

　Society of Chemical Industry (Newcastle Section).

Greenwich.

　Royal Observatory.

Kew.

　Royal Gardens.

Leeds.

　Geological Association.
　" The Naturalist."
　Philosophical and Literary Society.
　Yorkshire College.
　Yorkshire Naturalists' Union.

Leicester.

　Literary and Philosophical Society.

Leytonstone.

　Essex Field Club.

Liverpool.

　Biological Society.
　Free Public Library.
　Geological Society.

London.

　Anthropological Institute.
　British Archæological Association.
　British Association.
　British Museum.
　British Museum (Nat. Hist.).

England and **Wales**—*continued.*

London.

    Chemical Society.
    East India Association.
    Entomological Society.
    Geological Society.
    Geological Survey of Great Britain.
    Geologists' Association.
    Guildhall Library.
    Institution of Civil Engineers.
    Institution of Electrical Engineers.
    Institution of Mechanical Engineers.
    Institution of Naval Architects.
    Iron and Steel Institute.
    Linnean Society.
    London Institution.
    London Library.
    Meteorological Office.
    National Association for the Promotion of Technical and
        Secondary Education.
    Odontological Society.
    Patent Office Library.
    Pathological Society.
    Pharmaceutical Society.
    Physical Society.
    Quekett Microscopical Club.
    Royal Agricultural Society.
    Royal Asiatic Society.
    Royal Astronomical Society.
    Royal College of Physicians.
    Royal College of Surgeons.
    Royal Geographical Society.
    Royal Institute of British Architects.
    Royal Institution of Great Britain.
    Royal Medical and Chirurgical Society.
    Royal Meteorological Society.
    Royal Microscopical Society.
    Royal Society.
    Royal Society of Literature.
    Science and Art Department.
    Scientific News Office.
    Society of Biblical Archæology.

England and **Wales**—*continued.*

London.

Society of Chemical Industry (London Section).
Victoria Institute.
Zoological Society.

Manchester.

Free Public Library.
Geological Society.
Literary and Philosophical Society.

Marlborough.

Marlborough College Natural History Society.

Mirfield.

Yorkshire Geological and Polytechnic Society.

Newcastle-on-Tyne.

Natural History Society of Northumberland, Durham, and
Newcastle-on-Tyne.
North-East Coast Institute of Engineers and Shipbuilders.
North of England Institute of Mining and Mechanical
Engineers.

Nottingham.

Free Public Library.

Oxford.

Ashmolean Society.
Bodleian Library.
Historical and Archæological Society.
Radcliffe Library.
Radcliffe Observatory.

Penzance.

Royal Geological Society of Cornwall.

Plymouth.

Plymouth Institution.

Richmond.

" Kew " Observatory.

England and **Wales**—*continued.*

Salford.
> Royal Museum and Library.

Southport.
> Society of Natural Science.

Swansea.
> Royal Institution of South Wales.

Taunton.
> Somersetshire Archæological and Natural History Society.

Truro.
> Royal Institution of Cornwall.

Ireland.

Armagh.
> Observatory.

Belfast.
> Natural History and Philosophical Society.

Dublin.
> Geological Survey of Ireland.
> National Library of Ireland.
> Royal Academy of Medicine.
> Royal College of Physicians.
> Royal College of Science.
> Royal College of Surgeons.
> Royal Irish Academy.
> Royal Society of Antiquaries.
> Royal University.
> Trinity College.

Dunsink.
> Observatory.

Londonderry.
> Magee College.

Scotland.

Edinburgh.
> Advocates' Library.
> Geological Society.

Scotland—*continued.*

Edinburgh.

Highland and Agricultural Society.
Museum of Science and Art.
Royal Botanic Garden.
Royal College of Physicians.
Royal Medical Society.
Royal Observatory.
Royal Physical Society.
Royal Scottish Society of Arts.
Royal Society.

Glasgow.

Institution of Engineers and Shipbuilders.
Mitchell Library.
Natural History Society.
Philosophical Society.

Inverness.

Gaelic Society.

BRITISH COLONIES AND OTHER POSSESSIONS.

Australia.

Adelaide.

Royal Society of South Australia.

Brisbane.

Queensland Museum.

Melbourne.

Geological Society of Australasia.
Observatory.
Patents Office.
Public Library.
Royal Society of Victoria.

Sydney.

Department of Mines.
Linnean Society of New South Wales.
Royal Society of New South Wales.
University Library.

Canada.

    Halifax.

        Nova Scotia Institute of Science.

    Montreal.

        Canadian Society of Civil Engineers.
        M'Gill University.
        Natural History Society.

    Ottawa.

        Geological Survey of Canada.
        Patent Office.

    Quebec.

        Literary and Historical Society.

    Toronto.

        Canadian Institute.

Cape of Good Hope.

    Cape Town.

        Royal Observatory.
        South African Library.

Hong Kong.

        Observatory.

India.

    Bombay.

        Royal Asiatic Society.

    Calcutta.

        Asiatic Society of Bengal.
        Geological Survey of India.
        Meteorological Office.

    Nungumbaukum (Madras).

        Observatory.

Jamaica.

    Kingston.

        Institute of Jamaica.

Malta.

        Public Library.

New Zealand.

    Wellington.

        New Zealand Institute.

        Registrar-General.

Tasmania.

    Hobart.

        Royal Society of Tasmania.

EUROPE (CONTINENTAL).

Austria.

    Brünn.

        Naturforschender Verein.

    Gratz.

        Naturwissenschaftlicher Verein für Steiermark.

    Innsbruck.

        Das Ferdinandeum.

        Naturwissenschaftlich-Medicinischer Verein.

    Prague.

        Königliche Böhmische Gesellschaft der Wissenchaften.

    Trieste.

        Società Adriatica di Scienze Naturali.

    Vienna.

        Anthropologische Gesellschaft.

        Kaiserliche Akademie der Wissenschaften.

        K. K. Central-Anstalt für Meteorologie und Erdmagnetismus.

        K. K. Geographische Gesellschaft.

        K. K. Geologische Reichsanstalt.

        Oesterreichische Gesellschaft für Meteorologie.

        K. K. Zoologisch-Botanische Gesellschaft.

Belgium.

    Brussels.

        Académie Royale de Médecine.

        Académie Royale des Sciences.

        Société Malacologique de Belgique.

    Louvain.

        L'Université.

Belgium—*continued.*

    Uccle.
        L'Observatoire Royal.

Denmark.

    Copenhagen.
        Kongelige Danske Videnskabernes Selskab.

Finland.

    Helsingfors.
        Société des Sciences.

France.

    Bordeaux.
        Académie des Sciences.
        Société Linnéenne.
        L'Observatoire.
        Société de Médecine et de Chirurgie.
        Société des Sciences Physiques et Naturelles.

    Cherbourg.
        Société des Sciences Naturelles.

    Dijon.
        Académie des Sciences.

    Marseilles.
        Faculté des Sciences.
        Société Scientifique et Industrielle.

    Meudon.
        L'Observatoire.

    Montpellier.
        Académie des Sciences et Lettres.
        Faculté de Médecine.

    Paris.
        Académie des Sciences de L'Institut.
        Dépôt de la Marine.
        École des Mines.
        École Normale Supérieure.
        École Polytechnique.
        Faculté de Médecine.

France—*continued.*

> Paris.
>> Feuille des Jeunes Naturalistes.
>> Jardin des Plantes.
>> Monaco, S. A. S. le Prince de.
>> L'Observatoire.
>> Revue Scientifique.
>> Société Académique Indo-Chinoise de France.
>> Société d'Encouragement pour L'Industrie Nationale.
>> Société Entomologique de France.
>> Société Française de Physique.
>> Société de Géographie.
>> Société Géologique de France.
>> Société Météorologique de France.
>> Société Zoologique de France.

> Rouen.
>> Académie des Sciences et Belles Lettres.

> Toulouse.
>> Académie des Sciences.

Germany.

> Berlin.
>> Deutsche Geologische Gesellschaft.
>> Gesellschaft für Erdkunde.
>> Königliche Preussiche Akademie der Wissenschaften.
>> Königliche Universität.
>> Physikalische Gesellschaft.

> Bremen.
>> Naturwissenschaftlicher Verein.

> Breslau.
>> Schlesische Gesellschaft für Vaterländische Cultur.

> Chemnitz.
>> Königliches Sächsisches Meteorologisches Institut.

> Danzig.
>> Naturforschende Gesellschaft.

> Dresden.
>> Verein für Erdkunde.

Germany—*continued*.

Emden.
> Naturforschende Gesellschaft.

Erlangen.
> Physikalisch-Medicinische Societät.

Frankfurt-am-Main.
> Senckenbergische Naturforschende Gesellschaft.
> Zoologische Gesellschaft.

Freiburg-im-Breisgau.
> Naturforschende Gesellschaft.

Giessen.
> Oberhessische Gesellschaft für Natur- und Heilkunde.
> Grossherzogliche Universität.

Görlitz.
> Naturforschende Gesellschaft.

Göttingen.
> Königliche Gesellschaft der Wissenschaften.

Halle.
> Kaiserliche Leopoldino-Carolinische Deutsche Akademie der
> Naturforscher.
> Naturwissenschaftlicher Verein für Sachsen und Thüringen.

Hamburg.
> Naturwissenschaftlicher Verein.

Heidelberg.
> Naturhistorisch-Medizinischer Verein.
> Universität.

Jena.
> Medicinisch-Naturwissenschaftliche Gesellschaft.

Karlsruhe.
> Grossherzogliche Sternwarte.

Kiel.
> Königliche Sternwarte.
> Universität.

Königsberg.
> Königliche Physikalisch-Ökonomische Gesellschaft.

Germany—*continued.*

    Landshut.
        Botanischer Verein.

    Leipzig.
        Astronomische Gesellschaft.
        Königliche Sächsische Gesellschaft der Wissenschaften.
        Königliche Sternwarte.

    Munich.
        Königliche Bayerische Akademie der Wissenschaften.

    Osnabrück.
        Naturwissenschaftlicher Verein.

    Potsdam.
        Astrophysikalisches Observatorium.

    Rostock.
        Universität.

    Stuttgart.
        Verein für Vaterländische Naturkunde in Württemberg.

    Würzburg.
        Physikalisch-Medicinische Gesellschaft.

Holland.   (*See* NETHERLANDS.)

Hungary.

    Budapest.
        Magyar Tudományos Akadémia.   Die Ungarische Akademie
            der Wissenschaften.

    Kolozsvár.
        Erdélyi Muzeum-Egylet.   Das Siebenbürgische Museum.

Italy.

    Bologna.
        Accademia delle Scienze dell' Istituto.

    Florence.
        Biblioteca Nazionale Centrale.
        Reale Istituto di Studi Superiori.

    Milan.
        Reale Istituto Lombardo di Scienze, Lettere ed Arti.
        Regio Osservatorio Astronomico di Brera.
        Società Italiana di Scienze Naturali.

Italy—*continued.*

Modena.

Regia Accademia di Scienze, Lettere ed Arti.

Naples.

Stazione Zoologica.

Società Reale, Accademia delle Scienze.

Palermo.

Reale Istituto Tecnico.

Società di Scienze Naturali ed Economiche.

Rome.

Accademia Pontificia de' Nuovi Lincei.

Reale Accademia dei Lincei.

Reale Comitato Geologico d'Italia.

Reale Ufficio Centrale di Meteorologia e di Geodinamica, Collegio Romano.

Siena.

Reale Accademia dei Fisiocritici.

Turin.

Reale Accademia delle Scienze.

Venice.

Ateneo Veneto.

Reale Istituto Veneto di Scienze, Lettere ed Arti.

Luxemburg.

Société des Sciences Naturelles.

Netherlands. (*See also under* Java.)

Amsterdam.

Koninklijke Akademie van Wetenschappen.

Koninklijke Zoologisch Genootschap; "Natura Artis Magistra."

Delft.

École Polytechnique.

Haarlem.

Musée Teyler.

Hollandsche Maatschappij der Wetenschappen.

Rotterdam.

Bataafsch Genootschap.

Utrecht.

Provinciaal Genootschap van Kunsten en Wetenschappen.

Norway.

　　Bergen.

　　　　Bergenske Museum.

　　Christiania.

　　　　Kongelige Norske Frederik's Universitet.

　　Trondhjem.

　　　　Kongelige Norske Videnskabers Selskab.

Portugal.

　　Coimbra.

　　　　Universidade.

　　Lisbon.

　　　　Académia Real das Sciencias.

Roumania.

　　Bucarest.

　　　　Academia Română.
　　　　L'Institut Météorologique de Roumanie.

Russia.

　　Kazan.

　　　　Imperatorsky Kazansky Universitet.

　　Moscow.

　　　　Roumiantreff Public Museum.
　　　　Société Impériale des Naturalistes.

　　Odessa.

　　　　Société des Naturalistes de la Nouvelle-Russie.

　　St. Petersburg.

　　　　Académie Impériale des Sciences.
　　　　L'Institut Impériale de Médicine Expérimentale.
　　　　L'Observatoire Physique Central.
　　　　Société Impériale de Géographie.

　　Tiflis.

　　　　L'Observatoire Physique.

Servia.

　　Belgrade.

　　　　Académie Royale de Serbie.

Sicily.　　(*See* ITALY.)

Spain.

Cadiz.

Instituto y Observatorio de Marina de San Fernando.

Madrid.

Real Academia de Ciencias.

Sweden.

Göteborg.

Kongl. Vetenskaps och Vitterhets Samhälle.

Lund.

Universitet.

Stockholm.

Kongl. Svenska Vetenskaps-Akademie.
Sveriges Geologiska Undersökning.

Upsala.

Universitet.

Switzerland.

Basel.

Naturforschende Gesellschaft.

Bern.

Allgemeine Schweizerische Gesellschaft.
Naturforschende Gesellschaft.

Geneva.

Institut National Genevois.
Société de Physique et d'Histoire Naturelle.

Lausanne.

Société Vaudoise des Sciences Naturelles.

Lucerne.

Naturforschende Gesellschaft.

Neuchâtel.

Société des Sciences Naturelles.

Zurich.

Naturforschende Gesellschaft.
Das Schweizerische Polytechnikum.

Turkey.

Constantinople.

British Institute.

ASIA.

China.

    Shanghai.

        Royal Asiatic Society (China Branch).

Japan.

    Tokiô.

        Asiatic Society of Japan.

        Imperial University.

Java.

    Batavia.

        Bataviaasch Genootschap van Kunsten en Wetenschappen.

        Magnetical and Meteorological Observatory.

AMERICA (NORTH).

Mexico.

    México.

        Sociedad Cientifica " Antonio Alzate."

    Tacubaya.

        Observatorio Astronómico Nacional.

United States.

    Albany.

        New York State Library.

    Austin.

        Texas Academy of Science.

    Baltimore.

        Johns Hopkins University.

    Berkeley.

        University of California.

    Boston.

        American Academy of Arts and Sciences.

        Boston Society of Natural History.

    Buffalo.

        Buffalo Medical and Surgical Journal.

        Society of Natural Sciences.

United States—*continued.*

Cambridge.
> Harvard University.

Chapel Hill (N. C.).
> Elisha Mitchell Scientific Society.

Charleston.
> Elliot Society of Science and Art of South Carolina.

Chicago.
> Academy of Sciences.
> University.

Cincinnati.
> Observatory.
> Mechanics' Institute.

Concord.
> New Hampshire State Library.

Granville (Ohio).
> Denison University.

Madison.
> Wisconsin Academy of Sciences.

Meriden (Conn.).
> Scientific Association.

Minneapolis (Minn.).
> Geological and Natural History Survey.

Mount Hamilton (California).
> Lick Observatory.

Newhaven (Conn.).
> American Journal of Science.

New York.
> American Geographical Society.
> American Museum of Natural History.
> Columbia College Library.
> Linnean Society of New York.
> New York Academy of Sciences.
> New York Medical Journal.

Palo Alto (California).
> Stanford University.

United States—*continued.*

Philadelphia.
>> Academy of Natural Sciences.
>> American Philosophical Society.
>> Franklin Institute.
>> University of Pennsylvania.

St. Louis.
>> Academy of Science.

Salem (Mass.).
>> Essex Institute.

San Francisco.
>> California Academy of Sciences.
>> Geographical Society of California.
>> Geographical Society of the Pacific.

Topeka (Kansas).
>> Kansas Academy of Science.

Washington.
>> Bureau of Education.
>> Smithsonian Institution.
>> Surgeon-General's Office (United States Army).
>> United States Coast and Geodetic Survey.
>> United States Commission of Fish and Fisheries.
>> United States Department of Agriculture.
>> United States Geological Survey.
>> United States National Museum.
>> United States Naval Observatory.

AMERICA (SOUTH).

Argentine Republic.

Cordoba.
>> Academia Nacional de Ciencias.

La Plata.
>> Museo de la Plata.

Brazil.

Rio de Janeiro.
>> Museo Nacional.
>> Observatorio.

São Paulo.
>> Museu Paulista.

Royal Dublin Society.

FOUNDED, A.D. 1731. INCORPORATED, 1749.

EVENING SCIENTIFIC MEETINGS.

THE Evening Scientific Meetings of the Society and of the associated bodies (the Royal Geological Society of Ireland and the Dublin Scientific Club) are held on Wednesday Evenings, at 8 o'Clock, during the Session.

Authors desiring to read Papers before any of the Sections of the Society are requested to forward their Communications to the Registrar of the Royal Dublin Society *at least* ten days prior to each Evening Meeting, as no Paper can be set down for reading until examined and approved by the Science Committee.

The copyright of Papers read becomes the property of the Society, and such as are considered suitable for the purpose will be printed with the least possible delay. Authors are requested to hand in their MS. and necessary Illustrations in a complete form, and 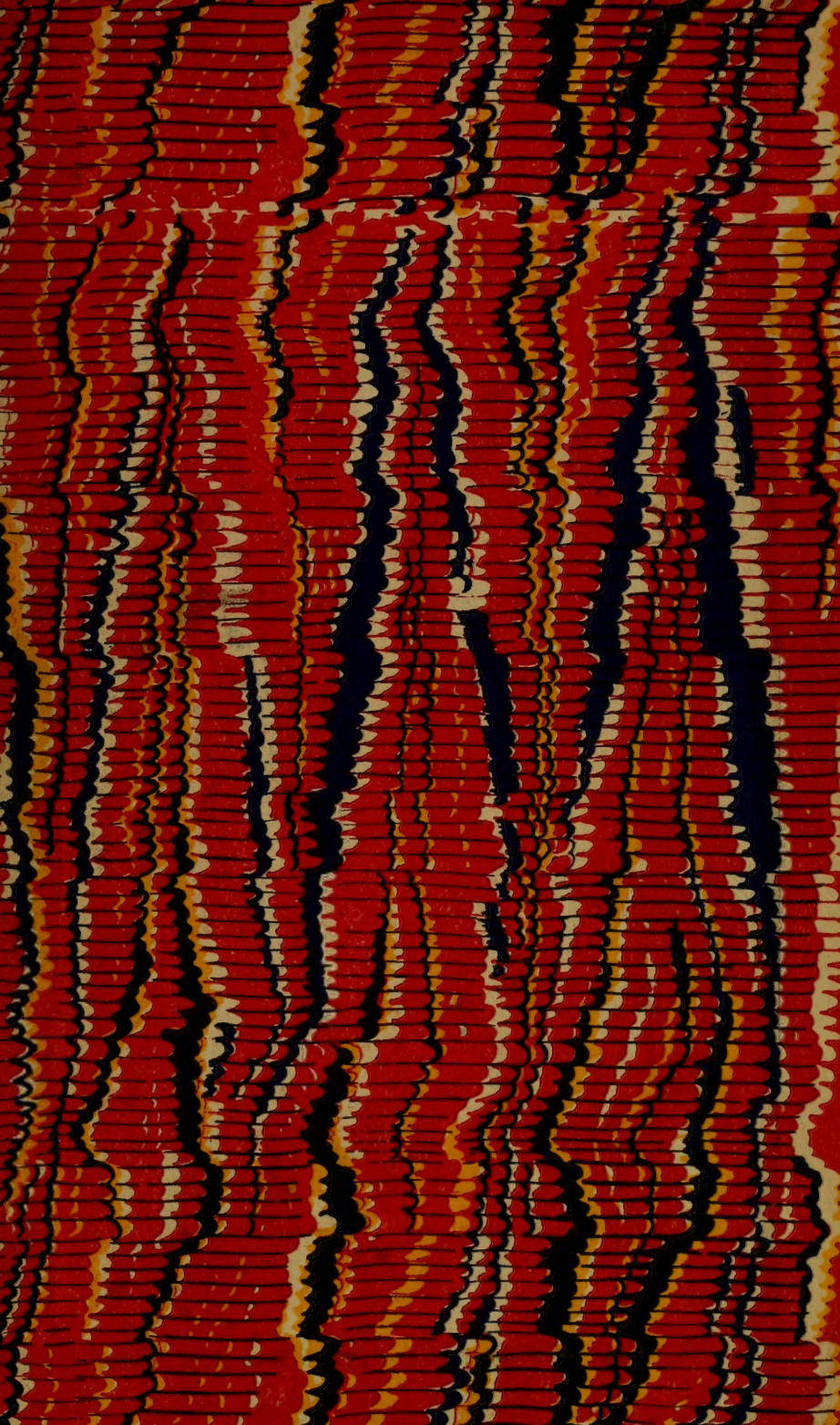ready for transmission to the Editor.